The Influence of Water-Drinking with Meals upon the Digestion and Utilization of Proteins, Fats and Carbohydrates

By HENRY ALBRIGHT MATTILL

A.B. Western Reserve University, 1906
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THESIS

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN PHYSIOLOGICAL CHEMISTRY IN THE GRADUATE SCHOOL OF THE UNIVERSITY OF ILLINOIS

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STUDIES ON WATER DRINKING. VIII.[1] THE UTILIZATION OF INGESTED FAT UNDER THE INFLUENCE OF COPIOUS AND MODERATE WATER DRINKING WITH MEALS.

By H. A. Mattill.

Introduction.

Current Theories.—Notwithstanding the fact that many persons are accustomed to drinking considerable amounts of water with their meals, and with no apparent ill effect, the opinion has been and still is somewhat general, and the statement almost axiomatic, that the use of water with meals is injurious and harmful. The arguments advanced in proof of this statement are typical of that quasi-scientific reasoning which assumes, *a priori*, the truth of certain antecedents; the consequents must therefore logically be true.

A concrete statement of the views as generally held by many in the medical profession and, through them, by the general public, may be cited from Carrington:[2]

"We can lay down the definit and certain rule that it (water) should never be drunk at meals, and preferably not for at least one hour after the meal has been eaten. The effect of drinking water while eating is, first, to artificially moisten the food, thus hindering the normal and healthful flow of saliva and the other digestive juices; secondly, to dilute the various juices to an abnormal extent; and thirdly, to wash the food elements through the stomach and into the intestins before they have had time to become thoroughly liquefied and digested. The effects of this upon the welfare of the whole organism can only be described as direful."

It needs no argument to prove that such effects upon the organism would be direful, but the proof that such effects follow the drinking of water with meals is entirely wanting.[1] On the contrary, experiments have been made which show specifically that certain of these effects do not follow.

[1] Presented in abstract at the New Haven meeting of the American Society of Biological Chemists, December, 1910; Proceedings, Vol. II, p. xiv. This paper and the two following were presented in abstract before the Second International Congress of Alimentary Hygiene and of the Rational Feeding of Man, Brussels, October, 1910; Proceedings, Vol. I, Section II, p. 30. They were also presented by Mr. Mattill to the Graduate School of the University of Illinois, in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

[2] Although little experimental evidence substantiates the statement it will be granted at the start, that any circumstance that induces insufficient mastication of the food before swallowing is undesirable, the reason being that salivary digestion in the stomach is not to be overlooked and further, that the movements of the alimentary tract are insufficient to bring about the necessary fineness of division of the food particles. Therefore in all the discussion and experimental work that follows, water with meals means the taking of water when the mouth is empty; the food is masticated, as usual without the aid of water; water is never used to wash down the products of incomplete mastication.

1. The Effect of Water on the Digestive Juices. Saliva.—The degree of dryness of the food determins the amount of saliva poured out upon it, the drier the food the larger the amount of saliva that is secreted.[2] The kind of food introduced into the mouth determins also the physical properties of the saliva. It will be argued, therefore, that the taking of water with food prevents the normal secretion of saliva. In the experiments that follow, however, since water is not mixed with the food while this is in the mouth, the effect of water on the secretion of saliva is only a residual one, that is, an effect due to the presence of whatever water may remain in the mouth after swallowing.

Gastric Juice.—The influence of water upon gastric secretion was investigated by Pavlov and Khizhin[3] and still earlier by Heidenhain[3a] and by Sanotskii[3b] and their findings have been confirmed by later investigators, especially by Foster and Lambert.[4] The first mentioned workers in experiments on dogs with Pavlov stomachs and divided vagi showed that water stimulates the flow of gastric juice if comparatively large amounts (400–500 cc.) are ingested, but that with small amounts (100–150 cc.) in half the cases observed, not the least trace of secretion could be found. "It is only a prolonged and widely spread contact of the water with the gastric mucous membrane, which gives a constant and positive result."[3] Since the vagi were divided, the effect of the water must have been that of a chemical excitant. The later investigators[4] in experiments on the influence of water when taken with food showed that water causes not only a more voluminous secretion but also a more acid secretion.

Pancreatic Juice and Bile.—Water also acts as an excitant of pancreatic juice.[5] When 150 cc. of water are introduced into the stomach of a dog the pancreas begins to secrete, or augments its flow, within a few minutes after the water has entered the stomach. Since this amount of water, according to Pavlov, is insufficient to excite a flow of gastric juice, the secretion of pancreatic juice is not secondary to a secretion of the other, but is a direct result of the presence of water in the stomach. In dogs with Pavlov pancreas fistulas Togami[6] has shown that in response to both chemical and psychical stimuli there is evident parallelism between the secretion of gastric juice and of pancreatic juice. Acids of all kinds act as powerful excitants of pancreatic secretion. The flooding of the small intestin with larger amounts of acid chyme means an increased production of pancreatic secretion and a consequent increased flow of pancreatic juice. The biliary secretion has also been shown to respond to pancreatic secretion and the digestive properties of the pancreatic juice are augmented in a very marked way by the bile. Hence the increased acidity of the gastric contents as a result of the stimulating action of water causes a much more active digestive juice to be poured out upon the chyme as it reaches the intestin. Furthermore, certain other experiments from this

laboratory have shown increased pancreatic activity[6a] to follow water-drinking with meals, the index being the output of fecal amylase.[7, 7a]

Intestinal Juice.—The effect of water in the intestin has not been demonstrated as clearly as its effect in the middle portion of the alimentary canal. Under ordinary circumstances the intestinal juice is secreted only by those portions of the tube with which the food is in contact. Mechanical stimulation is effective in producing a secretion but it is shown that such secretion is comparatively poor in enzymes and contains only salt and water. When poured out upon food the intestinal juice is rich in enterokinase, but much more powerful stimulants even than food in this regard are the pancreatic enzymes; which one of them is active in this direction is not yet known.

2. The Effect of Dilution upon Enzyme Activity.—The reactions brought about by enzymes are like all other chemical reactions in that they are reversible. They do not proceed to completion unless the products of the reaction are removed as formed. In a concentrated solution the point at which the reaction comes to a standstill is reached sooner than in a dilute one, and in many instances the equilibrium of a reaction mixture may be disturbed by dilution; the reaction is forced toward completion if water is added. In the light of this fact the increased activity of gastric juice that has been observed under the influence of water may be due to the effect of dilution fully as much as to the increased acidity that accompanies it.

3. The Rapidity of the Passage of Food as Affected by Water.—That water begins to pass the pylorus soon after its ingestion has been shown by von Mering.[8] To a large dog with duodenal fistula 500 cc. of water were given through the mouth; within 25 minutes 495 cc. were collected through the fistula. It is probable that when water ingestion is accompanied by the taking of food the passage of water is somewhat delayed. In the experiments to be described it was shown that the equivalents of from one-half to three fourths of the amount of water ingested during a meal, if this amount was large, may be voided in the urine within 45–90 minutes thereafter. These facts would seem to give some ground for the contention that the food elements might be washed through the stomach and into the intestin before they were properly liquefied and digested.

It has been shown by Cohnheim[8a] however that when the fundus is filled with food material a specific mechanism comes into play after the introduction of liquid. Along the smaller curvature there is formed a trough which connects the antrum pylori with the cardiac opening, and this trough has been demonstrated anatomically by Kaufmann.[8b] In this trough water flows past the bolus of food lying in the stomach without as much as washing any of the exterior away. Even when digestion is at its height and when gastric juice is being secreted in large amounts, almost neutral water is often found leaving the stomach. Cohnheim

further states that there is no dilution of the stomach contents by liquid food, and the accurate regulation of the pyloric sphincter is not disturbed whether water is taken with the meal or not.

From the considerations thus briefly reviewed the facts regarding the drinking of water with meals seem to be the following: (1) The ingestion of large amounts of water with meals not only does not hinder the normal flow of digestive juices, but acts as an excitant to their flow; (2) the digestive juices are not made less efficient by dilution; on the contrary, enzyme action is more complete the greater the dilution, within limits; (3) while the food elements might perhaps be washed through the stomach into the intestin more rapidly than is usual (contrary to Cohnheim's belief), yet over against this is the greater amount and efficiency of the digestive juices. The first two conclusions have been substantiated by experiment. The question as to the completeness of the digestion of the food and the degree to which it is utilized under the conditions of greater dilution and supposedly more rapid movement through the alimentary canal has had but little consideration.

The only experimental evidence upon the utilization of the fat of food as influenced by the amount of water taken with meals comes from an investigation by Ruzicka.[9] His conclusions were drawn from data obtained in two experimental periods of two days each, on a bread and meat diet, preceded, separated and followed by a day of milk diet. No attempt was made to have the fat intake uniform from day to day. During the first period water was taken at times and in amounts found desirable, except that none was taken during or immediately following a meal. In the second period approximately the same amount of water was ingested but it was taken during and immediately following the meals. The feces data include dry matter, nitrogen, fat, ash, and carbohydrate by difference. Simple ether extraction was employed in determining fat. The balance of utilization was 94.5 per cent. in the first period as against 95.1 per cent. in the second. The author draws the negative conclusion that a moderate water ingestion at meal time has no harmful influences on the utilization of the food. He emphasizes the adaptability of the organism and supposes that it is a matter of the rapid absorption of the superfluous water. More specific conclusions than these were hardly justified, since neither diet nor water ingestion was absolutely uniform as to time and amount, the water ingestion being particularly variable; it ranged from 300 to 522 cc. at meal time.

The Feces.—The nature and composition of human feces seems generally to be misunderstood. A recent statement is that the feces are chiefly the unabsorbed residues of intestinal excretions.[10] Another statement is to the effect that the feces consist chiefly of bacteria.[10a] A microscopical examination easily shows, however, that these claims are not true. The composition of feces as given by Schmidt and Strasburger[11] is as follows:

(1) Indigestible material in the food.

(2) Undigested material, which has for some reason escaped the action of the digestive juices.

(3) Residues of the digestive juices.

(4) Bacteria and the products of fermentation and putrefaction.

(5) Products of the epithelial wall, such as decayed cells, leucocytes, etc.

Fats are almost always found in feces, the amount being increased by an increase in the fats in the food. In addition to the food as a source of fat are the digestive juices and the cells of the alimentary epithelia which contain both fats and lipoids.

Many investigators believe that the percentage utilization of a given foodstuff in an available diet is a subject whose importance has been exaggerated. It is said that the percentage differences are so small as to be inconsiderable, particularly in view of the fact that only small quantities of a given substance are involved. Perhaps from the standpoint of the mere existence of the organism this may be true, but the question of continued efficiency is not a negligible one. It seemed probable, at least, that an examination of the feces with regard to their content of fat might give an indication as to the efficiency with which the fat of the food was digested under the influence of water ingestion with meals.

Description.

General Plan.—The general plan of these experiments was to determin in a preliminary period the digestibility of fat in subjects living on a uniform diet. During a second period, with no change in diet, a given volume of water was to be added to that taken normally with each meal, and in a final period the conditions of the preliminary period should again obtain.

The subjects of the experiments were normal men, on the staff of assistants in the Department of Chemistry. The daily periods began and ended at 7 A.M., and the program was as follows: Body weights were taken at 7 A.M., after urinating and defecating. So regular the routine became that in only two or three instances throughout the eight to nine weeks of the experiments defecation did not come at this time. To insure accuracy, body weights were always taken without clothing. The morning meal was taken at 7.30, the noon meal at 12 or 12.15, and the evening meal at 5.30 or 5.45. The three meals were identical and consisted of graham crackers, butter, peanut butter, milk and water. Smaller quantities of water were taken at stated hours during the day. The men went about their duties as usual throughout the day and evening.

The urine was collected in 24-hour samples, the last portion being that passed before weighing in the morning. The urine was analyzed for total

nitrogen, ammonia, urea, creatinine, creatine,[11a] total and ethereal sulfates, and indican.[11b]

The analysis of the feces was made on each individual stool. As passed it was weighed and thoroughly mixed until uniform throughout. The samples for analysis were then weighed out as quickly as possible to prevent loss by evaporation, which is very rapid. Charcoal was used as a "marker" to facilitate the separation of the feces of different periods; where the uniformity of the diet is not to be interfered with this method is the most satisfactory. One or two capsules (0.2 gram) of finely divided charcoal were taken before breakfast on the day beginning a new period. With but few exceptions the separations thus obtained were very distinct and entirely satisfactory.

The length of time between the taking of food and the appearance of the feces therefrom has been variously given. A recent statement is that particles fed to a man are not usually passed in his feces for two or three days.[10] The observations of the present experiments support the opinion as given by Strasburger[13] that normally this period is 24 hours. Throughout these experiments the charcoal given on one morning appeared in the last portions of the feces passed the next morning, in all but two cases, in both of which the separations were from an ordinary mixed diet, that is, at the beginning or at the end of the experiment.

Methods.—All analyses were made on fresh feces without previous drying, and were always made in duplicate unless the amount of material available was not sufficient. The analysis of the fresh stool[12] to our mind is the ideal method of feces examination. Certainly in view of Shimidzu's findings, mentioned below, we can place no dependence upon data obtained from the analysis of the dried sample.[13a] The analysis of each individual stool in the fresh condition of course demands the expenditure of much more time and energy than are necessitated in the analysis of composit samples of dried feces. However, the added accuracy and the greater value of the data obtained by means of the "fresh" procedure certainly warrant the extra effort.

The method selected for the determination of fat was that proposed and developed by Kumagawa and Suto[14] with the modifications added by Inaba.[15] This method, above all others, yields a product that can be considered to be more nearly pure fat than that yielded by any other methods of extraction.[1] The method as described by its authors is carried out upon air-dried materials but for our determinations no air-drying was employed. Shimidzu[15a] has shown that the drying of tissues on the

[1] This statement does not apply to the method of Folin and Wentworth (*J. Biol. Chem.*, 7, 421–6 (1910)), with which we have had no experience. It appeared after the completion of this work.

water bath previous to the determination of their fat content by this method causes a loss of fat which may exceed 10 per cent. The loss is probably due to oxidation. It is probable, therefore, that in the determination of fat in feces by this method, the use of fresh material without previous drying yields most accurate results. The procedure involves the saponification of 5–10 grams of fresh feces by a 5 *N* sodium hydroxide solution for several hours; this is overneutralized with 20 per cent. hydrochloric acid, taking care to keep the mixture from becoming hot, and the acid liquid is extracted with ether. Any precipitate remaining is dissolved in hot normal sodium hydroxide, heated for about 15 minutes and extracted with ether; the acid aqueous solution that was first drained off is added and all the fat and fatty acid remaining go over into the ether portion. The combined ethers are evaporated, the residue purified by absolute ether and lastly by petroleum ether, and dried at 60° to constant weight. The fatty acids so obtained were crystallin and almost colorless; care in preventing overheating during the first neutralization and a sufficient drying of the last ether residue before taking up in petroleum ether are essential to obtaining them in pure form.

It is evident that by this method the unsaponifiable substances are determined along with the fatty acid and the authors[14] give a satisfactory procedure by which these may be determined. It was shown by Inaba[15] that the unsaponifiable substances in the feces amount to about 10 per cent. of the total fatty acids determined and that a separation of these substances is of importance, if most accurate results are desired. Inasmuch as a uniform diet was fed in these experiments, any difference in the fat content of the feces from one period to another was probably subject to no correction on this account.

Experiments on Copious Water Drinking with Meals.

General Description.—The first experiments on Subjects H and W may now be considered in detail. Subject H was a tall well-proportioned man weighing 70.22 kilograms at the beginning of the experiment. He had been on a diet of comparatively simple variety and as he was not fond of milk and drank neither tea nor coffee, water comprized the chief liquid portion of his diet. Subject W was of smaller stature and weighed 63.2 kilograms at the beginning of the experiment. He was accustomed to the diet as offered by a club table of the better grade and usually drank water sparingly. He regularly smoked a cigar after the evening meal and did so throughout the experiment. Both subjects were put upon the same uniform diet of graham crackers, butter, peanut butter and milk. It contained 180 grams of fat per day distributed for each food and meal as follows:

	Amount.	Fat.
Oatmeal crackers......	150 grams	11.7 grams
Peanut butter.........	20	9.2
Butter................	25	21.1
Milk..................	450 (cc.)	18.0
Water.................	100 cc.	....
		Total, 60.0

In addition, 200 cc. of water were taken at 10 A.M., at 3 P.M., and again in the evening or just before retiring, making a total of 900 cc. of water per day during the three-day preliminary period.[1] On the morning of the fourth day before breakfast charcoal was taken and during the five days following one liter of water was added to the menu of each meal, making 1100 cc. per meal and a total of 3900 cc. per day. On this diet both subjects record a feeling of fulness that sometimes became temporarily slightly uncomfortable. It was necessary to urinate frequently especially during the first few hours after the meal; for a short time after eating there was a desire to remain quiet and inactive, as is the case after any full meal; within three-quarters of an hour or an hour, approximately half the water taken at the meal was voided. Both subjects record that the feeling of fulness and lassitude noted immediately after meals became less marked after the second day of the water period. Both felt perfectly well at all times and had normal appetites. After the fourth day H records that he did not notice the feeling of fulness which followed the high water ingestion of the first few days of the water period.

The period of copious water ingestion lasted five days. On the morning of the sixth day charcoal capsules were taken before breakfast and during that and the two following days the diet of the preliminary period was resumed. The experiment ended with the taking of charcoal on the morning of the fourth day of this period.

Discussion of Results.—The data upon the excretion of fat in the feces during these three periods are given in Tables I and II.

Subject H, Table I.—The data show that the average daily excretion of fat during the preliminary period was 8.37 grams, during the water period 7.16 grams and 9.22 grams during the final period. The digestion and absorption of fat were seemingly more complete during the water period than during the preliminary period and upon the withdrawal of water the excretion of fat rose to an amount that was higher than before the period of water ingestion. A slight gain in weight was recorded,

[1] The water supply (see Fowler and Hawk, *J. Exp. Med.*, 12, 390 (1910)) of this community is from deep wells and for use in these experiments it was softened by the addition of five liters of saturated lime water to thirty liters of the tap water. After standing several hours or a day the precipitate was filtered off. This water had an agreeable taste; its alkalinity was 70 to phenolphthalein, 180 to methyl orange, and its hardness determined by soap solution was 92 parts per million.

70.29 kilograms on the morning of the first day of water and 70.88 kilograms on the morning of the first day after the water. This gain of 600 grams was not lost for at least three months thereafter.

TABLE I.—SUBJECT H.

Preliminary period. 3 days.		Water period. 5 days.		Final period. 3 days.	
Number of stool.[1]	Fat.	Number of stool.[1]	Fat.	Number of stool.[1]	Fat.
1	3.23	5	2.16	10	6.06
2	5.16	6	5.65	11	2.14
3	9.73	7	3.58	12	8.79
4	7.00	8	16.59	13	10.68
Total	25.12	9	7.80	Total	27.67
Average	8.37	Total	35.78	Average	9.22
		Average	7.16		

TABLE II.—SUBJECT W.

Preliminary period. 3 days.		Water period. 5 days.		Final period. 3 days.	
Number of stool.	Fat.	Number of stool.	Fat.	Number of stool.	Fat.
1	9.22	5	5.80	11	5.56
2	10.60	6	1.31	12	7.76
3	3.85	7	5.98	13	1.84
4	7.00	8	6.41	14	6.34
Total	30.67	9	7.01	Total	21.50
Average	10.22	10	2.64	Average	7.17
		Total	29.15		
		Average	5.83		

Subject W, Table II.—During the preliminary period there was an average daily excretion of 10.22 grams of fat in the feces. During the water period this was reduced to an average of 5.83 grams per day and in the final period it rose to 7.17 grams per day, an amount only slightly above that of the water period. From these data it would appear that during the period of copious water drinking the fats of the food were more completely digested and absorbed than either before or after this period and that this effect of the water drinking was not temporary but more or less permanent. In the case of W also a slight gain in weight accompanied the experiment. On the morning of the first day of water his weight was 63.46 kilograms; at the end of this period it was 64.16 kilograms. This gain of 700 grams might be attributed to retained water, except for the fact that it was not lost subsequently. After the lapse of three months, during which time the subject was on an ordinary mixed diet, his weight was identically the same as at the end of the water period of this experiment. While great significance can not be attached to so small a change in weight, even granted that it is not due to water, it must nevertheless be borne in mind that the diet throughout the experiment was absolutely uniform with the exception of the water ingestion.

[1] Weights of all stools are included in the third paper of the series.

It seemed reasonable to assume that the decreased excretion of fat during the water period was due to more complete utilization as a result of the large volumes of water ingested, and several explanations could be suggested. Of first importance was the direct stimulating effect of water upon the digestive juices. In his first experiments on dogs Pavlov[3] found that a large amount of water (500 cc.) caused a flow of gastric juice, while a small amount (150 cc.) in half the cases observed had not the least effect. He states that the important factor is a prolonged and widely spread contact of water with the gastric mucous membrane. This contact can hardly be called prolonged because of the rapid passage of water through the pylorus; this very circumstance, however, might make a large volume of water effective as against a small volume in that the former did secure a more widely spread contact than the latter, and perhaps also for a slightly longer period of time. To obtain further information on this point it was considered worth while to make another experiment upon the effect of a smaller amount of water taken with meals, but whose use should extend over a longer period of time.

Experiments on Moderate Water Drinking with Meals.

Description, Methods, Etc.—The plan of the experiment was exactly the same as that of the previous one. Two subjects were maintained on a uniform diet of small water content for several days. Then during a period of ten days in which the same diet was continued, 500 cc. of water in addition to the usual amount were taken with each meal. In the final period the conditions of the preliminary period were again in force. The daily routine was the same as in the preceding experiment. Charcoal was used to separate the feces of the different periods and the analyses were made on each individual stool in a fresh condition.

After an interval of about three months W, of the preceding experiment, again served as subject. In the meantime he had been at the same table as before, had had much the same kind of food, and in general the same dietary habits with the exception that he had formed the habit of taking more water with his meals than before the first experiment. His weight at the beginning of this experiment was 64.18 kilograms, almost exactly the same as at the end of the first experiment.

Subject E was of the average build and weighed 73.6 kilograms. His habits of eating were irregular. During the previous year he had for a time lived on one substantial lunch-counter meal a day,[1] later on two, and during the months preceding the experiment on three at a regular table. He was accustomed, ordinarily, to taking considerable amounts of water with his meals.

The food of each meal, and its fat content were as shown:

[1] Howe, Mattill and Hawk, *J. Am. Chem. Soc.*, 33, 570 (1911).

(In grams.)	Amount.	Fat.
Oatmeal crackers	150	12.9
Peanut butter	20	9.2
Butter	25	21.1
Milk	400 (cc.)	16.0
Water	100 cc.	
	Total,	59.2

The diet of W was slightly reduced from what it had been before and was as follows:

(In grams.)	Amount.	Fat.
Oatmeal crackers	125	10.8
Peanut butter	20	9.2
Butter	25	21.1
Milk	400 (cc.)	16.0
Water	100 cc.	
	Total,	57.1

In addition, each man took 200 cc. of water at 10 A.M., at 3 and at 8.30 P.M., making a total water ingestion of 900 cc. per day during the preliminary period. During the water period the addition of 500 cc. of water to each meal made the total water ingestion 2400 cc. per day during that time.

Discussion of Results. Subject W.—On the diet as given, some little difficulty was experienced in obtaining nitrogen equilibrium in the preliminary period. Charcoal was taken on the morning of the eighth day, but for the sake of keeping uniformity in the feces data it seemed best not to change the diet. Six days passed and on the morning of the fourteenth day charcoal was again taken and water added to the regular diet. The separation of the preliminary period into two parts proved to be a very important incident in view of what the feces data show (Table III).

TABLE III.—SUBJECT W.

I. Preliminary period. 7 days.		II. Preliminary period. 6 days.		Water period. 10 days.		Final period. 5 days.	
Number of stool.	Fat.	Number of stool.	Fat.	Number of stool.	Fat.	Number of stool.	Fat.
1	12.30	7	4.20	14	1.84	24	3.54
2	3.19	8	7.47	15	10.18	25	6.58
3	4.23	9	8.07	16	4.70	26	3.36
4	4.71	10	10.52	17	9.70	27	8.56
5	12.20	11	3.21	18	3.89	28	5.54
6	5.06	12	5.97	19	7.54	29	4.08
Total	41.69	13	1.90	20	1.74	Total	31.66
Average	5.96	Total	41.24	21	11.59	Average	6.33
		Average	6.89	22	7.85		
				23	8.72		
				Total	67.75		
				Average	6.78		

During the time that intervened between his two experiments Subject W, as has been mentioned, while on an ordinary mixed diet, continued the habit of taking considerable water with his meals. As is evident from the diet of the preliminary period the amount of water taken was small and was, in fact, much less than he was accustomed to use. While this restricted amount of water did not immediately make itself felt in the first few days of the experiment, it did begin to show in the latter part of the preliminary period by a seemingly less complete digestion and absorption of fat. This is evident in an increase in the average daily fecal output of fat during the second part of the preliminary period. The average daily amount of fat excreted in the first part of this period was 5.96 grams as against 6.89 grams in the second part. Since the charcoal separation of this preliminary period into two portions was clear and definit this increase in fat in the feces during the latter part seems to mean a less efficient digestion and utilization of the fat of the food. That this evidence did not appear until some days after the amount of water had been reduced indicates, as in the first experiment, that the beneficial effect which water had upon digestion and absorption did not cease with the withdrawal of water, but was more or less permanent beyond the time during which water was taken with the meals. The evidence given by this finding was entirely unlooked for and seems to be of great importance.

Attention should also be called to the comparison of the fat data of this preliminary period with those of the preliminary period of the first experiment, Table II. The average daily amount of fat excreted in the preliminary period of the first experiment was 10.22 grams as against 5.96 in the second. The average percentage utilization of fat in the former was 94.3 per cent. as against 96.5 per cent. in the latter. These data showing so pronounced an improvement in the digestion and utilization of fat are on an individual living on the same kind of food, but separated by a period of three months in which water drinking with meals was practiced. From these results the conclusion as to the effect of water drinking with meals upon the utilization of fat is further strengthened.

It is further seen in Table III that the average daily excretion of fat in the preliminary period, 6.89 grams, suffered but little change in the water period, 6.78 grams, but was slightly decreased, 6.33 grams, in the final period. Just why this decrease should have come in the final period rather than during the water period is not clear. Perhaps there is a lag in the appearance of the results of water drinking, just as it has been shown that its effects are more or less permanent. In this case the moderate amount of water may have had a stimulatory effect that was not evident during the water period but made itself felt during the period following. The question of individuality probably enters in also. From

a study of the data on Subject W during this experiment it may be concluded that the effect of moderate water drinking with meals upon digestion is in the same direction as that of copious water drinking but somewhat less marked.

Subject E.—An examination of Table IV shows the variations in fat excretion from one period to another to be small although similar to those obtained before. The output of fat fell from 6.61 grams per day in the preliminary period to 6.39 grams per day under the influence of moderate water drinking, and again rose to 6.70 in the final period.

Again it appears that the effect of drinking water in moderate amounts with meals is in the same direction as when large amounts are used, although the differences observed are of a smaller order of magnitude; as with the copious amounts, absolutely no harmful effects were to be observed. With moderate amounts of water the inconvenience of disposing of an unusual quantity of liquid after the meal was removed, and the lethargic effects of a full meal, such as were noted under the experiment on copious water drinking, were also avoided.

TABLE IV.—SUBJECT E.

Preliminary period. 7 days.		Water period. 10 days.		Final period. 4 days.	
Number of stool.	Fat.	Number of stool.	Fat.	Number of stool.	Fat.
1	3.79	9	3.33	20	2.79
2	1.51	10	5.85	21	5.60
3	8.96	11	3.96	22	7.75
4	11.63	12	8.20	23	7.88
5	3.92	13	9.78	24	2.77
6	8.66	14	6.50		
7	5.20	15	7.07	Total	26.79
8	2.63	16	3.63	Average	6.70
		17	2.90		
Total	46.30	18	9.59		
Average	6.61	19	3.10		
		Total	63.91		
		Average	6.39		

The results just given were obtained on subjects one of whom (W) had lately become accustomed to drinking with meals; the other of whom (E) habitually took considerable water with his meals. In each case the organism, though accustomed to the presence of water in the alimentary tract during digestion, responded to an increase in its amount by a better utilization of the fat of the food. The results obtained, therefore, probably represent the minimum rather than the maximum effect that may be obtained by moderate water drinking with meals, and are such as might safely be expected in any individual, but especially in one not accustomed to drinking water under these conditions.

The Effect of Copious Water Drinking with Meals upon an Habitual Water Drinker.

At this point an answer was sought to the question as to whether a very large water ingestion with meals would show its effect upon digestion even though relatively large amounts of water were habitually taken at meal time. For this investigation Subject E seemed very well fitted; during the experiment on moderate water drinking he had frequently made it his boast that he was not drinking more water with his meals during the water period than was his custom. It seemed advizable therefore to try upon E the effect of such amounts of water as would be copious for his digestive mechanism.

Description.—Continuing with the same diet as in the final period of the previous experiment, a period of six days was made the preliminary period for this experiment. During the five days following this period an addition of one and one-third liters of water was made to the water ingestion of each meal. This is a larger amount of water than was used in the first experiment on copious water drinking, where only 1000 cc. additional were taken with each meal. A final period of three days closed the experiment. On the very first day of this large water ingestion Subject E records that he had no trouble in drinking all of the water, nor was any discomfort experienced throughout the experiment.

TABLE V.—SUBJECT E.

Preliminary period. 6 days.		Water period. 5 days.		Final period. 3 days.	
Number of stool.	Fat.	Number of stool.	Fat.	Number of stool.	Fat.
1	2.75	8	3.17	14	5.58
2	4.28	9	1.84	15	3.87
3	10.87	10	11.35	16	8.69
4	5.90	11	4.46	17	0.82
5	7.44	12	7.33		
6	8.59	13	3.53	Total	18.96
7	1.97			Average	6.24
		Total	31.68		
Total	41.80	Average	6.34		
Average	6.97				

Discussion of Results.—Table V shows that the average daily excretion of fat in the preliminary period, 6.97 grams, fell to 6.34 grams in the water period, and the daily average value for the final period, 6.24 grams, was even slightly less than for the water period. The effect of copious water drinking with meals is seen to be in the same direction when the organism is accustomed to water drinking as when it is not, except that when water drinking with meals is habitual the results are less striking than otherwise.

Inferences and Discussion.

All of the observations made have pointed to a decreased elimination of fat in the feces when water was taken with meals, indicating a more

complete utilization of the fat of the food than without the water ingestion, and in most instances the evident better digestion continued for several days beyond the period during which an increased water ingestion was practiced. A large amount of water was more efficient in this regard than a small one and a more pronounced result was obtained in persons not used to water drinking with meals than in those for whom it was habitual.

The results of our experiments warrant more than a negative conclusion. The ingestion of water along with the food secures a better utilization of the fat of the food as shown by a diminished excretion of fat in the feces. It is possible to explain this result on the basis of four different facts.

(1) The Stimulating Action of Water upon the Gastric Secretion and Independently upon the Secretion of Pancreatic Juice and Bile.

The facts observed by Pavlov and his co-workers[3] mentioned above, and the findings of Foster and Lambert[4] as to the stimulating action of water upon the gastric secretion in dogs have also been observed in human beings with gastric and esophageal fistulas. In some of the older investigations it was shown[16, 17, 18] that a purely psychic secretion, such as is noted in dogs, is not as pronounced in man as in these animals. A pleasant taste of food in the mouth caused a flow of gastric juice in some instances, but whether, in general, such a secretion of gastric juice in man arizes indirectly through stimulation carried by the blood or by the nerves, or whether it is due directly to the contact of substances with the mucous membrane of the stomach is uncertain. The observations of Bogen,[19] Kaznelson,[20] and Sommerfeld[21] upon patients with gastric fistulas have clearly demonstrated a psychic secretion. Most varied stimuli through taste, smell, and sight of food, and through sounds associated with the preparation of food called forth a secretion of gastric juice. In the subject examined by Lavenson[22] no psychic secretion was demonstrable but water was found to be a definit though not powerful stimulus. Sommerfeld[21] was able to show that water had a stimulating action upon the gastric secretion, and further, that the mere drinking of water, after the manner of sham feeding, caused a flow of gastric juice. It is claimed that saliva is not a factor in inducing gastric secretion. The evidence adduced by Hemmeter[23] as to a salivary hormone producing increased flow of gastric juice could not be verified by Loevenhart and Hooker.[24] The stimulating factor may be mastication itself, including the taste phenomena and also the desirability of the food.

In human beings as well as in the lower animals investigated the acidity of the gastric juice is found to vary with the kind of food. The findings of Foster and Lambert[4] on dogs with accessory stomach indicate not only

a more voluminous but also a more acid secretion when water is taken with food and they suggest an automatic control in the stomach, such that the chyme, no matter what its state of dilution, always has the same optimum acid concentration. The increased acidity noted in the accessory pouch may not actually exist in the stomach proper; here, by dilution, the acid concentration may remain unchanged. Certain other experiments reported from this laboratory[24a] apparently confirm this view. If the stimulation of water is entirely a chemical one, however, it is difficult to see why the mucosa of the pouch, which is not in contact with the water, should respond as readily as the stomach itself, even though it has the same nerve and blood supply. Any effect which the accessory pouch shows may possibly be less marked than the one actually secured in the stomach proper.

Whether an increased acidity and digestive power of the gastric juice is of immediate importance in the digestion of fat is not clear. The cleavage of fat by gastric lipase is very minimal in the normal acid reaction of the stomach except when the fats are in the form of a natural emulsion. London and Versilova[25] showed that in dogs the cleavage of fat fed in such a form (egg-yolk) rose as high as 32 per cent. in the stomach, due in part to gastric lipase and in part to regurgitated duodenal juice. A similar observation has been made recently by Levites.[26] Kaznelson[20] found a lipase in the gastric juice of her patient. According to Lavenson's observations[22] a regurgitation of bile and pancreatic juice in the stomach occurred with great constancy when oil was given.

No absorption of fat takes place in the stomach. In the experiments of London and Versilova[25] where one-third of the fat administered was split in the stomach no absorption took place until this material reached the ileum. As a result of their findings Camus and Nicloux[27] and also Stire[28] emphasize the unimportance of gastric lipase. The fats undergo practically no change in the stomach, and when they do it is as a result of a regurgitated duodenal secretion.

In view of these facts the importance, for fat digestion, of the greater quantity of gastric juice, or a greater acidity, or both, as a result of the stimulating action of water with the food is to be sought rather in the effect upon the secretion of the bile and the pancreatic juice.

(2) The Acid Chyme as an Excitant for the Flow of Pancreatic Juice and Bile.

The formation of secretin from prosecretin is the result of an acid reaction of the duodenum; the larger the amount of acid the greater the stimulation given to the secretory action of the pancreas, and the flow of bile is regulated by the same mechanism. That the efficiency of bile in aiding the digestion of fats by pancreatic lipase is due to the bile acids

has again been shown recently by Terroine.[29] The same investigator has also shown[30] that at an optimum concentration of pancreatic juice and of esters or whatever other substances are undergoing cleavage, the hydrolysis is activated proportionately by increasing quantities of bile salts.

Fat in small amounts is a regular constituent of pancreatic juice and especially of the bile, and an increase in these secretions should cause increased elimination of fat in the feces unless a compensation was found. This increased excretion is not found, but, on the contrary, a constant *decrease* is observed under the influence of water drinking with meals. It follows from this that the digestibility of fat during the period of water drinking with meals was increased even beyond what the data indicate, since part of the excreted fat might come from the larger amounts of digestive juices secreted under the stimulating influence of water. And furthermore inasmuch as the fat values for the stools derived by the Kumagawa-Suto technic include any cholesterol present, the increased output of biliary cholesterol during the water period would also be a factor tending toward an apparently augmented output of fecal fat during this interval.

(3) Heightened Peristalsis and Increased Blood Pressure as Factors in the More Complete Digestion and Utilization of Fat.

Peristalsis is known to increase with the volume of material within the intestin. Whether a large amount of a liquid mass is as efficient in this regard as an equal bulk containing less water is uncertain. The effect of dilution and increased peristalsis brought on by purgatives was shown by Ury[31] not to increase the amount of soluble foodstuffs or of their products in the feces. His observations were limited to soluble protein and to sugar.

Water begins to pass the pylorus very soon after its ingestion, and is quickly absorbed. During the time that this water is in the tissues and is flowing in the blood stream, the increased volume causes a rise in blood pressure similar to the rise regularly following a meal. In duplicate feeding experiments on a dog with gastric fistula Dobrovolskii[32] found that after bleeding there was an almost complete stoppage of the process of digestion during the first 3 hours, due in part to the decreased blood pressure. No measurements of blood pressure were made during these experiments on water drinking; it seems reasonable to assume, however, that a greater blood pressure and a consequent stronger and more rapid heart beat might also be factors in the more complete absorption of the fat of the food when water is taken with meals.

Both of these factors, peristalsis and blood pressure, are to be investigated as to the effect which large volumes of water with meals have upon them.

(4) Dilution as a Factor in More Complete Utilization.

More important than any of the other factors, probably, is this one of dilution. Like all other chemical reactions, those brought about by enzymes are reversible. Governing these is the general principle expressed in LeChatelier's theorem which states that when a system in equilibrium is subjected to a constraint by which the equilibrium is shifted, a reaction takes place within the system which opposes the constraint, *i. e.*, one by which its effect tends to be destroyed. Processes within the system tend to counteract the effect of external changes. Thus the dilution of any solution in which the reaction $AB \rightleftarrows A + B$ had come to equilibrium would result in the formation of further amounts of A and B in order to increase the total concentration of dissolved material by way of counteracting the effect of dilution. The reaction would be driven toward the right and would be brought more nearly to completion. Looked at in another way such a reversible reaction as given above reaches an equilibrium whose constant is expressed by the equation $C_a \times C_b / C_{ab} = K$. The numerical value of this fraction as expressed by K remains unchanged whatever the total concentration of the solution may be. If the solution is diluted, causing a reduction in all three of the terms C_a, C_b and C_{ab}, the values C_a and C_b must diminish relatively less rapidly than C_{ab} in order that K should remain the same. And in order to accomplish this some of the substance whose concentration is C_{ab} is transformed into the substances whose concentrations are C_a and C_b. A concentrating of the solution would have the opposit effect. Now all of the hydrolytic cleavages occurring in digestion are of the type $AB \rightleftarrows A + B$, *i. e.*, a single substance is broken up into two or more products, and such reactions are brought the more nearly to completion the greater the dilution in which they take place. The corresponding synthetic reactions are accomplished by beginning with a high concentration of the corresponding decomposition products.

The failure to provide for the removal of the end-products, either by dilution or by dialysis, has often been shown to prevent a reaction from going to completion. In experiments upon the saponification of fats by pancreatic juice obtained by fistula from a dog Terroine showed[33] that the addition of oleic acid or of sodium oleate to olein emulsions rendered saponification of the latter more difficult. The addition of glycerol to suspensions of olive, castor, and cottonseed oils had the contrary effect of making them much more readily saponifiable, but this was due to the physical effect of the glycerol in making the emulsions more complete and more permanent by virtue of decreasing the surface tension. In his investigations upon human pancreatic juice Bradley[34] found that the undiluted juice acted on ethyl butyrate less rapidly than when diluted

1 : 10. The optimum dilution was found to lie between 1 : 15 and 1 : 20. In experiments on the effect of bile salts on pancreatic juice Terroine[35] found that the action was a physico-chemical one, directly upon pancreatic juice, that if the time of the action was prolonged digestion was retarded, and that if still more prolonged digestion was inhibited. Shorter periods resulted in maximum digestion.

In the light of these facts the better absorption and more complete utilization of the fats attendant upon water ingestion with meals are a result of the greater completeness of the hydrolytic cleavage under the influence of dilution and of the accompanying more rapid removal of the end-products.

Summary.

Experiments were performed on men living on a uniform diet; a preliminary period of small water ingestion was followed by a period of large water ingestion with meals, and this, in turn, by a final period with the original conditions.

When one liter of water additional was taken with meals the average daily excretion of fat in the feces was much reduced below that found when a minimum amount of water was taken with meals; one and one-third liters had a like effect; a similar but less marked reduction was observed when 500 cc. of water were taken with meals.

The decreased excretion of fat observed during water drinking with meals was usually evident for a number of days after water had ceased to be taken in large or moderate amounts with meals indicating that the beneficial influence of water was not temporary but was more or less permanent.

A slight gain in weight accompanied the water drinking and this gain was not subsequently lost.

After several months of moderate water drinking with meals a pronounced improvement in the digestibility of fat was observed, the percentage utilization having risen from 94.3 to 96.5.

The better digestion and absorption of fat was probably due to the following factors:

(1) Increased secretion of gastric juice and independently of pancreatic juice as a result of the stimulating action of water.

(2) Increased acidity of the chyme bringing about a more active secretion of pancreatic juice and bile.

(3) Increased peristalsis due to larger volume of material in the intestin and increased blood pressure due to rapidly absorbed water.

(4) A more complete hydrolysis of the fats by lipase due to increased dilution of the medium and consequent more rapid absorption.

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STUDIES ON WATER DRINKING: IX. THE DISTRIBUTION OF BACTERIAL AND OTHER FORMS OF FECAL NITROGEN AND THE UTILIZATION OF INGESTED PROTEIN UNDER THE INFLUENCE OF COPIOUS AND MODERATE WATER DRINKING WITH MEALS.

H. A. Mattill.

Introduction.

By far the larger part of the organic material eliminated in the feces is of unknown nature and composition. A knowledge of the source of fecal material is thereby made the more difficult to obtain. Three sources are usually considered as contributing to the nitrogenous material excreted as feces: (1) food residues, (2) residues of the digestive juices and cellular material from the intestinal wall, (3) bacteria and their products. Each of these in turn has been emphasized as the principal contributing agent, but no attempt seems ever to have been made to determin the "nitrogen partition" in the feces.

That the food residues of an available diet form any considerable part of the excreted material has had to be denied since the early work of Voit on fasting feces. In feeding experiments on dogs this investigator[1] showed that the amount of nitrogen in the feces was not proportional to the amount of meat fed. No muscle fibers or protein could be detected in the feces. Voit[2] showed that the material produced in an isolated loop of the intestin of a dog was of a similar composition and contained the same amount of nitrogen as the feces of the normal intestin through which food was passing. Prausnitz,[3] in experiments on men, showed that the composition of the feces varied with the diet and gave a definition of normal feces as those resulting from the eating of any food that is completely digested and absorbed. His data also show that the amount of nitrogen in the feces is uninfluenced by the amount in the food, although Schierbeck[4] finds considerable variation in this respect. Rubner[5] found that in man the amount of feces and its nitrogen content are determined entirely by the cellulose content of the diet. In the same way he found that on a milk diet the resulting fecal mass was almost directly proportional to the quantity of milk ingested.

It is entirely probable that on a diet whose constituents are not entirely available the amount of feces is increased by the undigested cellulose, and the nitrogen content is increased by the larger amount of digestive juices secreted because of the larger volume of food and the accompanying increased peristalsis.

About one-third of the dry matter of human feces consists of bacteria, and at least one-half of the nitrogen of feces is bacterial in its origin.[6,7,8]

Little is known as to the conditions upon which the growth of the intestinal flora depends. In herbivora, whose food materials contain large amounts of cellulose, the presence of organisms that bring about the decomposition and utilization of this substance is an advantage. Even so, only 45 per cent. of the energy of such food is utilized. In the intestin of carnivora the existing micro-organisms are limited to unabsorbed protein and the residue of the digestive juices for their food supply. In man, living upon a diet that contains food material of both the available and the unavailable kind, a condition midway between might be expected, just as the relative length of the intestin lies between that of herbivora and carnivora.

A recent claim of Schottelius[11] is that the presence of bacteria in the intestin of vertebrates is a desirable condition. Among their functions are the following: to prepare the food for absorption, to stimulate peristalsis, to inhibit the growth of pathogenic bacteria, and to render the body immune to bacterial poisons and to pathogenic organisms in general. The investigations looking toward a determination of the possibility of normal life with a steril alimentary canal have yielded conflicting results;[9,10] the nature of the animal, of its food and its digestive mechanism are all important factors in deciding the question.

Since the supply of nutriment for the bacteria of the lower intestin must consist mainly of the nitrogenous residues of the digestive juices and of the unabsorbed foodstuffs that reach the large intestin, we should expect a decreased bacterial growth when this food supply is decreased. An increase in unabsorbed residues of digestive juices and foodstuffs should result in an increased bacterial growth. It would seem reasonable to suppose, therefore, that any influence leading to the incomplete digestion and absorption of food, especially of its protein portion, in the alimentary tract would result in increased elimination of nitrogen in the feces, or in increased bacterial growth in the lower intestin, or in both of these conditions.

It was thought that evidence on both of these points might be valuable in determining the probable effect of water ingestion with meals.

The only earlier experimental evidence as to the influence of water drinking with meals upon the utilization of food was obtained by Ruzicka[12] in an experiment upon himself. The conditions and routine of his experiment are referred to in the previous paper on the utilization of fat. During the first 2-day period of his experiment when no water was taken with the meals, 118.4 g. protein were ingested, 17.9 g. excreted; during the second 2-day period when water was taken with the meals, 125.9 g. protein were ingested, 16.5 g. excreted. Protein utilization was 84.9 per cent. in the first period and 86.9 per cent. in the second. Neither

diet nor water ingestion was sufficiently uniform to allow any but the most general conclusions to be drawn.

More specific evidence comes from an investigation made in this laboratory by Fowler and Hawk.[18] Their subject was brought to nitrogen equilibrium on a constant and uniform diet and continuing this diet one liter of water was added to each meal for a time of five days; this was followed by a short final period in which the original conditions held. It appears that the average fecal output per day and the average dry matter per day in the feces were both much less during the water period than during either of the other periods, and that the average amounts during the final period were less than those of the preliminary period. More detailed examination of the feces was confined to the determinations of total and bacterial nitrogen on one stool in each of the three periods. These findings showed that both these forms of nitrogen were much reduced in amount during the period of copious water ingestion and that after water ceased to be used in unusual amounts these values did not immediately return to the values found for the preliminary period but were still lower than those during the final period. The authors concluded that these findings indicated a more economical utilization of the protein of the food. During the water period of five days the subject gained approximately two pounds in weight, and continued to gain for a number of months after the end of the experiment and the return to ordinary mixed diet. It could not be said that the water drinking had no effect, nor that it had an ill effect.

These conclusions as to the digestibility and availability of the foods during water-drinking were based upon analyses of but three stools, one in each of the three periods. The importance of the conclusion reached seemed to justify more extensive experiments along the same line, experiments in which each individual stool of the whole investigation should be subjected to similar examination. The present investigation was therefore planned on this basis.

Description.

General Plan.—The general plan and routine of the experiment has been described in the preceding paper.

Methods.—All analyses were made on fresh feces without previous drying. The samples usually weighed out with the approximate weights were as follows:

(*a*) Two 2-gram samples for total nitrogen.

(*b*) Two 2-gram samples for bacterial nitrogen.

(*c*) Two 2-gram samples for acid-alcohol extract.

Total Nitrogen.—During the earlier experiments dried feces were used for the total nitrogen determinations, with unsatisfactory results due to loss of nitrogen during the drying. That there is such a loss the

data clearly show; this has been observed before.[14,14a] In the later experiments the determination of total nitrogen was made upon the fresh material with satisfactory results.

Bacterial Nitrogen.—The method for bacterial nitrogen is described in another paper from this laboratory.*

Residue Nitrogen.—As explained more in detail under the determination of bacterial nitrogen, residue nitrogen is that which comes from the well-washed sediments in the sedimentation for bacterial nitrogen. It represents undigested and insoluble nitrogen that occurs in the larger particles of the feces.

Extractive Nitrogen.—The sample for acid-alcohol extract was rubbed up in a small Erlenmeyer flask with a known volume of 95 per cent. ethyl alcohol made 0.2 per cent. acid with hydrochloric acid. The flask was stoppered and was allowed to stand at room temperature for a week, being shaken up at least once each day. Nitrogen was then determined on an aliquot portion (one-half) of the alcohol originally added. This represents such nitrogenous end-products as are below the proteose stage, and the soluble nitrogen of the digestive juices and of the pigments. Almost invariably this amount is less than that obtained by a similar extractive method on the bacterial sample as described under bacterial nitrogen. This may be due to the greater fineness of division that is secured in the case of the latter and perhaps also to the solvent action of the 0.2 per cent. hydrochloric acid used in making the bacterial suspensions.

All determinations of nitrogen of whatever form were made by the Kjeldahl method. Instead of metallic mercury, copper sulfate was used as catalyst in the digestion.

Experiments on Copious Water Drinking with Meals.

As mentioned before, subjects H and W were put on the same diet; the amounts had to be altered before nitrogen equilibrium was reached. The quantity and composition as finally given were as follows:

	Amount (per meal).	Nitrogen.
Graham crackers	150 grams	2.087 grams
Peanut butter	20 "	0.882 "
Butter	25 "	0.020 "
Milk	450 (cc.)	2.360 "
	Total	5.349
Protein		33.44 grams
Protein per day		100.32

On this diet a condition of nitrogen equilibrium was attained approx-

* Mattill and Hawk, *J. Exp. Med.*, 14, 433 (1911).

imately at the end of the third day. The exact nitrogen balance may be seen from the following:

Subject H.	Nitrogen in feces	2.153
	Nitrogen in urine	14.036
	Nitrogen in excreta	16.189
	Nitrogen in food	16.046
		—0.143
Subject W.	Nitrogen in feces	2.385
	Nitrogen in urine	14.534
	Nitrogen in excreta	16.919
	Nitrogen in food	16.047
		—0.873

TABLE I.—SUBJECT W.

		Nitrogen distribution.						Percentage of total fecal nitrogen found in.		
	Number of stool.	Fecal nitrogen (det.).	Fecal nitrogen (calc.).	Bacterial + soluble nitrogen.	Bacterial nitrogen.	0.2 per cent. HCl-soluble nitrogen.	Acid-alc.-soluble nitrogen.	Bacterial.	HCl-soluble.	Acid-alc.-soluble.
Preliminary period. 3 days.	1	1.738	1.911	1.737			0.445			23.3
	2	2.333	2.536	2.305			0.599			23.6
	3	0.913	0.961	0.874			0.193			20.1
	4	1.649	1.747	1.588			0.586			33.5
	Total	6.633	7.155	6.504			1.823			
	Average	2.211	2.385	2.168	1.279	0.889	0.608			25.5
					(calc.)	(calc.)				
Water period. 5 days.	5		(1.387)	1.296			0.280			15.2
	6	0.301	0.287	0.268			0.085			28.2
	7	1.337	1.433	1.339			0.416			29.0
	8	1.499	1.593	1.489			0.402			25.2
	9	1.653	1.771	1.655			0.458			25.9
	10	0.554	0.640	0.598			0.175			27.3
	Total		7.111	6.645			2.401			
	Average		(1.422)	1.329	0.784	0.545	0.480			33.4
					(calc.)	(calc.)				
Final period. 3 days.	11	1.410	1.459	1.364	0.817	0.547	0.456	56.0	37.5	31.2
	12	1.805	1.896	1.772	0.970	0.802	0.571	51.2	42.3	30.1
	13	0.448	(0.431)	0.403	0.294	0.109	0.122	65.6	24.3	27.2
	14	1.329	1.499	1.401	0.866	0.535	0.373	57.8	35.7	24.9
	Total	4.992	5.286	4.940	2.947	1.993	1.522			
	Average	1.664	1.762	1.647	0.982	0.664	0.507	55.7	37.7	28.8
					0.972	0.675				
					(calc.)	(calc.)				

Discussion of Data from Subject W, Table I.—As mentioned before the determinations of fecal nitrogen in this experiment were unsatisfactory because of the loss of volatil nitrogenous compounds in drying. That nitrogen was lost is very evident from the values of bacterial + soluble nitrogen which are in almost all cases larger than the corresponding total nitrogen. The so-called bacterial + soluble nitrogen comes from the determination of bacterial nitrogen and its significance will be clear by referring to the description of the method as given in a recent article.[1] If the acid suspension after removing the last sediment of non-bacterial substance is not treated with alcohol, but is directly transferred to Kjeldahl flasks, the nitrogen so determined is not only bacterial but includes in addition all nitrogen that is soluble in 0.2 per cent. hydrochloric acid or that has become so during the time of manipulation. This datum is spoken of as bacterial + soluble nitrogen. In later experiments it was shown that the ratio of total nitrogen to bacterial + soluble was fairly constant at 1.10 in the preliminary period and 1.07 in the following periods. Applying this factor to the values under bacterial + soluble nitrogen the values under fecal nitrogen (calc.) are obtained. Although these are not values obtained by analysis, they are more correct than those actually obtained for the reasons given. Taking either of these values, however, the average daily amount of total nitrogen excreted during the water period is only two-thirds of the average daily amount excreted during the preliminary period, and about four-fifths the average daily amount of the final period. The average daily amount in the final period is only slightly higher than that of the water period, and only three-fourths of what it was in the preliminary, showing that the good effect of the water is not immediately lost.

The question as to the kind of fecal nitrogen that was decreased in amount cannot be answered on the basis of analytical data, since the bacterial and acid-soluble nitrogen were not separated during the early part of the experiment. From later experiments in which this separation was made, a factor was calculated and found to be very uniform for different subjects throughout the various periods. On this basis 59 per cent. of the combined bacterial + soluble nitrogen is nitrogen belonging to bacterial substance. That the factor as applied does not fall far short of representing actual conditions may be gathered from the close agreement between the calculated values and those obtained by actual analysis of the stools of the final period. Applying this factor to the values for combined bacterial + soluble nitrogen the nitrogen of bacterial substance in the preliminary period was 1.279 grams per day, in the water period 0.784 gram per day, and in the final period 0.972 gram per day. These values indicate that bacterial nitrogen was de-

[1] Mattill and Hawk, *J. Exp. Med.*, 14, 433 (1911).

creased under the influence of copious water drinking and furthermore, in common with the results found for total fecal nitrogen, this condition was not transitory but more or less permanent. The same statement may be made regarding the nitrogen soluble in 0.2 per cent. hydrochloric acid. The acid-alcohol-soluble nitrogen averaged 25.5 per cent. of the total fecal nitrogen during the preliminary period, 33.4 per cent. during the water period, and 28.8 per cent. during the final. This may mean that the digestion during the water period resulted in nitrogenous end products which are more soluble. This increased percentage of acid-alcohol-soluble nitrogen in the feces during the water period does not indicate decreased absorption, for the *absolute* amount of this form of nitrogen in the feces is *decreased* from 0.608 gram during the preliminary period to 0.480 gram in the water period and rizes only slightly above this value, 0.507 gram, during the final period, showing that absorption of the soluble end products is more complete under the influence of water. More probably, however, this form of nitrogen represents the residual portion of digestive and intestinal juices which are known to increase in amount under the influence of water ingestion, especially the gastric and pancreatic secretions and the bile. If this is so, it is a very important fact, for even though during copious water ingestion, the flow of these secretions is stimulated, and as a result of increased peristalsis the amount of cast-off cellular material in the intestin is increased, the amount of fecal nitrogen instead of being increased, as, indeed, it must be from these sources, is, on the contrary, actually *decreased*. It follows from this that the digestibility of protein material during a period of copious water-drinking was increased even beyond what the data indicate, since part of the excreted nitrogen is known to come from the larger amounts of digestive juices secreted under the stimulating influence of water.

Discussion of Data from Subject H, Table II.—The values for total fecal nitrogen, either those determined directly on dry feces or those calculated directly from the bacterial + soluble nitrogen, show that the average daily excretion of nitrogen was 1.833 g. (detd.) during the preliminary period, 1.442 g. during the water period, and 1.636 g. during the final period. It was thus much less during the water period than during either of the others, and the average daily amount after the water was less than that before it.

As with subject W, the kinds of fecal nitrogen that suffered a decrease cannot be stated on the basis of analysis. The results on applying to the value for bacterial + soluble nitrogen the factor 0.59, which was obtained from later experiments, as has been explained, show that the average bacterial nitrogen per day was decreased from 1.155 in the preliminary to 0.875 in the water period, rizing to 1.044 in the final. The average daily output as determined for the final period is 1.128, showing

that the factor used is accurate. The same proportionate differences are to be noticed in the values for soluble nitrogen. It is evident that both bacterial and soluble nitrogen in the feces underwent a marked decrease during the period of copious water drinking.

TABLE II.—SUBJECT H.

	Number of stool.	Nitrogen distribution.						Percentage of total fecal nitrogen found in		
		Fecal nitrogen (detd.).	Fecal nitrogen (calc.	Bacterial + soluble nitrogen.	Bacterial nitrogen.	0.2 per cent. HCl soluble nitrogen.	Acid-alc.-soluble nitrogen.	Bacterial.	HCl-soluble.	Acid-alc.-soluble.
Prelim. period. 3 days.	1........	0.636	0.743	0.675			0.208			28.0
	2.......	1.214	1.427	1.297			0.342			24.0
	3........	2.206	2.654	2.413			0.756			28.5
	4........	1.443	1.635	1.486			0.653			39.9
	Total.........	5.499	6.459	5.871			1.959			
	Average......	1.833	2.153	1.957	1.155 (calc.)	0.802 (calc.)	0.653			30.3
Water period. 5 days.	5........	0.514	0.537	0.502			0.280			52.1
	6........	1.113	1.249	1.167			0.447			35.8
	7........	0.695	0.761	0.711			0.238			31.3
	8........	3.325	3.602	3.366			1.134			31.5
	9........	1.563	1.788	1.671			0.655			36.6
	Total.........	7.210	7.937	7.417			2.754			
	Average......	1.442	1.587	1.483	0.875 (calc.)	0.608 (calc.)	0.551			34.7
Final period. 3 days.	10........	1.229	1.415	1.322	0.819	0.503	0.503	57.9	35.6	35.6
	11........	0.442	0.477	0.446	0.302	0.144	0.119	63.3	30.2	24.9
	12........	1.510	1.763	1.648	1.082	0.566	0.563	61.4	32.1	31.9
	13........	1.726	2.028	1.895	1.180	0.715	0.671	58.2	35.3	33.1
	Total........	4.907	5.683	5.311	3.383	1.928	1.856			
	Average.....	1.636	1.894	1.770	1.128	0.643	0.619	59.6	34.0	32.7
					1.044 (calc.)	0.726 (calc.)				

The percentage of acid-alcohol-soluble nitrogen rose from an average of 30.3 in the preliminary to 34.7 during the water period and fell to 32.7 in the final, while the actual amount fell from 0.653 in the preliminary to 0.551 in the water and rose to 0.619 gram per day in the final period. The actual amount of this form of nitrogen was considerably decreased under the influence of water drinking. The suggestion may be made again that the increased percentage output was probably due to the increased volume of digestive juices, the secretion of which was stimulated by the ingestion of water.

Summary.

The findings on both subjects in this experiment show a decreased elimination of all forms of fecal nitrogen during the period in which water (1000 cc. additional) was taken with each meal. No ill effects could be seen and the beneficial effect of water was not temporary but was prolonged beyond the time during which water was taken.

Experiments on Moderate Water Drinking with Meals.

In the experiments upon protein utilization under the influence of a water ingestion of 500 cc. with each meal, the same general methods were employed. Total nitrogen determinations were made on the fresh moist material and the loss in volatil nitrogen compounds due to drying was thus avoided. A more accurate and trustworthy separation of the bacterial + soluble nitrogen was made by an efficient centrifugation of the final alcohol suspension from which the clear liquid had been pipetted off. The nitrogen of the precipitated material could more truly be called bacterial nitrogen, that of the liquid, acid-soluble nitrogen.

On the basis of the experience gained in this and similar investigations we cannot agree with certain statements made recently by Mendel and Fine[1] as to the determination of the total nitrogen content of feces. They say: "The error incident to this procedure (drying), however, did not appear to us to warrant serious attention, at least until certain details of metabolism operations, such, *e. g.*, as the accurate division of feces belonging to successive periods, reaching a higher stage of perfection." If we examin Tables I and II of the present paper it will be observed that *the values obtained by us for the combined bacterial and soluble nitrogen of fresh feces are in nearly every instance larger than the total nitrogen values obtained from the analysis of the same feces after drying.* We are firmly convinced that the ideal method of feces analysis embraces the examination of the individual stools in the *fresh* condition. This procedure, of course, entails much more labor than the less accurate practice of utilizing the dried feces, but we believe that the added accuracy richly compensates the investigator. In certain connections the individual fresh stools may be preserved for several days and an analysis made of a composit sample of the moist feces.[14b]

Throughout most of this experiment the values for bacterial nitrogen and for nitrogen in the alcohol extract of bacteria, that is the acid-soluble nitrogen, were determined along with a determination of the bacterial + soluble nitrogen, that is, the same suspension without alcohol treatment. The agreement between the last-named and the sum of the first two is very satisfactory; in almost all cases they would pass as duplicates. The fact that the alcohol used was not previously freed from pos-

[1] Mendel and Fine, *J. Biol. Chem.*, 10, 309 (1911).

sible traces of nitrogen may account for the uniformly higher values given by the sum of the separate alcohol-soluble and bacterial determinations.

It was found from these data that the bacterial nitrogen was 59 per cent. of the combined bacterial + soluble nitrogen and this ratio was used in the preceding experiment. The ratio of total fecal nitrogen to bacterial-soluble nitrogen used in the first experiment was obtained from the values for these forms in this experiment. In both Tables III and IV this was approximately 1.10 in the earlier periods and 1.07 in the later periods.

Acid-alcohol-soluble nitrogen was determined as before, and the determination of residue nitrogen was made throughout this experiment.

The diet of subject W, who had served before, was slightly reduced from what it had been in the preceding experiment. The amounts and composition were as follows:

	Amount (per meal).	Nitrogen.
Graham crackers	125 grams	1.776 grams
Peanut butter	20 "	0.868 "
Butter	25 "	0.015 "
Milk	400 (cc.)	1.917 "
		4.577
Protein		28.61
Daily protein		85.83

The diet of subject E consisted of

Graham crackers	150 grams	2.120 grams
Peanut butter	20 "	0.868 "
Butter	25 "	0.015 "
Milk	400 (cc.)	1.917 "
		4.920 "
Protein		30.75
Daily protein		92.25

For water ingestion see preceding paper.

Discussion of Data from Subject W, Table III.—Because of the difficulty experienced in obtaining nitrogen equilibrium the preliminary period of W was divided by taking charcoal on the eighth day, but with no change in diet. On the 13th day W's nitrogen balance was as follows:

Nitrogen in feces	1.360
Nitrogen in urine	12.361
Nitrogen in excreta	13.721
Nitrogen in food	13.731
	+0.010

The influence of a restricted amount of water and the latent period after which its effects appeared, as explained in the previous paper, are to be noted in the protein utilization as they were in the fat utilization. The average daily fecal nitrogen excretion during the first part of the preliminary period rizes from 1.275 to 1.360 in the second part, bacterial + soluble nitrogen from 1.142 to 1.233, acid-alcohol-soluble from 0.284 to 0.320, and residue nitrogen from 0.148 to 0.154. A comparison of the nitrogen data of this preliminary period with the nitrogen data of the preliminary period of the first experiment shows the average daily total fecal nitrogen output to be 2.385 in the first as against 1.275 in the second; bacterial + soluble nitrogen 2.168 in the first as against 1.142 in the second; acid-alcohol-soluble 0.608 as against 0.284. The average percentage utilization of protein in the first experiment was 86.3 per cent. as against 90.7 per cent. in the second. These data showing so pronounced an improvement in the digestion and utilization of protein are on an individual living on the same kind of diet, but separated by a period of three months in which water drinking with ordinary meals was practised.

With the fourteenth day 500 cc. of water were added to the diet of of each meal and this was continued for ten days. A five-day period followed in which the original conditions prevailed.

By referring to Table III it will be seen at once that the nitrogen of the various periods presents no striking differences.

The values for total, bacterial and other forms show fluctuations which are too small to admit of conclusions. The largest proportionate variation is seen in the residue nitrogen. This, as was explained, was obtained from the solid material that was sedimented in the procedure for bacterial nitrogen. Its percentage of the total nitrogen, 11.3, in the preliminary period, fell to 9.5 in the water period, and still lower, to 8.2 in the final period. If these small differences are significant, they point to a condition of better digestion.

Discussion of Data from Subject E, Table IV.—On the diet given, the nitrogen balance of Subject E at the end of the sixth day was as follows:

Nitrogen in feces	1.926
Nitrogen in urine	13.320
Nitrogen in excreta	15.246
Nitrogen in food	14.761
	—0.485

An examination of the data in Table IV again reveals no striking differences in the nitrogen values from one period to another. The variations in average daily amounts of nitrogen in its various forms are, as in the case of W, too small to be significant, with the possible exception of the

TABLE III.—SUBJECT W.

		Nitrogen partition.							Percentage of total fecal nitrogen found in				
	Number of stool.	Total fecal nitrogen.	Bacterial + soluble nitrogen.	Bacterial soluble separate.	Bacterial nitrogen.	0.2 per cent. HCl soluble nitrogen.	Acid-alc.-soluble nitrogen.	Residue nitrogen.	Bacterial + soluble nitrogen.	Bacterial.	0.2 per cent. HCl soluble.	Acid-alc.-soluble.	Residue.
Prel. per. I. 7 days.	1	2.152	1.906				0.460	0.323	88.6			21.4	15.0
	2	0.618	0.556				0.143	0.076	90.0			23.2	12.2
	3	0.878	0.789				0.213	0.100	89.9			24.3	11.4
	4	1.070	0.990				0.234	0.109	92.5			21.9	10.2
	5	3.075	2.760				0.684	0.269	89.8			22.3	8.8
	6	1.131	0.993				0.255	0.159	87.8			22.6	14.0
Total		8.924	7.994				1.990	1.035					
Average		1.275	1.142				0.284	0.148	89.6			22.3	11.6
Prel. per. II. 6 days.	7	0.845	0.790	0.816	0.483	0.336	0.190	0.071	93.6	57.2	39.5	22.5	8.4
	8	1.265	1.208	1.199	0.693	0.506	0.277	0.127	95.5	54.8	40.0	21.9	10.0
	9	1.491	1.324	1.388	0.791	0.597	0.362	0.132	88.8	53.0	40.1	24.3	8.9
	10	2.213	2.008	2.057	1.107	0.949	0.544	0.271	90.7	50.0	42.9	24.6	12.3
	11	0.673	0.574	0.549	0.287	0.262	0.161	0.109	85.3	42.6	39.0	23.9	16.1
	12	1.254	1.136	1.084	0.590	0.494	0.298	0.169	90.6	47.0	39.4	23.8	13.5
	13	0.418	0.355	0.358	0.194	0.163	0.088	0.044	85.1	46.6	39.1	21.8	10.5
Total		8.157	7.396	7.450	4.144	3.306	1.920	0.922					
Average		1.360	1.233	1.242	0.691	0.551	0.320	0.154	90.7	50.8	40.5	23.5	11.3

Water period 10 days.	14	0.388	0.352	0.368	0.200	0.168	0.103	0.028	90.6	51.4	43.3	26.5	7.2
	15	2.044	1.959	1.867	0.984	0.884	0.530	0.207	95.8	48.1	43.2	25.9	10.1
	16	1.029	0.990	0.986	0.563	0.424	0.249	0.083	96.3	54.7	41.2	24.2	8.0
	17	2.044	1.929	1.929	1.087	0.841	0.521	lost	94.4	53.2	41.2	25.5	....
	18	0.899	0.790	0.831	0.440	0.390	0.215	0.123	87.8	49.0	43.4	24.0	14.0
	19	1.616	1.510	1.495	0.873	0.621	0.404	0.163	93.4	54.0	38.4	25.0	10.1
	20	0.377	0.337	0.345	0.198	0.147	0.087	0.042	89.3	52.5	39.1	23.0	11.1
	21	2.355	2.249	2.254	1.298	0.957	0.583	0.195	95.5	55.1	40.6	24.8	8.3
	22	1.672	1.533	1.549	0.881	0.668	0.409	0.172	91.7	52.7	40.0	24.5	10.3
	23	1.918	1.751	1.813	0.996	0.817	0.498	0.211	91.3	51.9	42.6	26.0	11.0
Total		14.343	13.400	13.437	7.520	5.917	3.599	1.224					
Average		1.434	1.340	1.344	0.752	0.592	0.360	0.136	93.4	52.4	41.3	25.1	9.5
Final period 5 days.	24	0.775	0.730	0.724	0.416	0.307	0.184	0.062	94.2	53.7	39.6	23.8	8.0
	25	1.497	1.383	1.391	0.823	0.568	0.355	0.099	92.4	55.0	38.0	23.7	6.6
	26	0.758	0.694	(0.694)	0.461	0.233	0.195	0.079	91.6	60.9	30.8	25.7	10.5
	27	1.845	1.738	1.955	1.160	0.795	0.488	0.163	94.2	62.9	43.1	26.5	8.8
	28	1.238	1.153	1.201	0.758	0.444	0.292	0.100	93.1	61.2	35.8	23.6	8.1
	29	0.875	0.830	0.872	0.539	0.333	0.207	0.070	94.8	61.6	38.1	23.6	8.0
Total		6.988	6.528	6.837	4.157	2.680	1.721	0.573					
Average		1.398	1.306	1.368	0.832	0.536	0.344	0.115	93.4	59.5	38.4	24.6	8.2

TABLE IV.—SUBJECT E.

		Nitrogen distribution.							Percentage of total fecal nitrogen found in				
		Total fecal nitrogen.	Bacterial + soluble nitrogen.	Bacterial soluble separate.	Bacterial nitrogen.	0.2 per cent. HCl soluble nitrogen.	Acid-alc.-soluble nitrogen.	Residue nitrogen.	Bacterial + soluble.	Bacterial.	0.2 per cent. HCl soluble.	Acid-alc.-soluble.	Residue.
Prel. period. 7 days.	1......	1.141	0.945				0.236	0.159	82.8			20.7	13.9
	2......	0.461	0.457				0.106	0.056	99.1			23.0	12.1
	3......	2.420	2.251				0.530	0.235	93.0			21.9	9.7
	4......	2.867	2.591				0.679	0.312	90.4			23.7	10.9
	5......	1.219	1.104				0.262	0.130	90.6			21.5	10.7
	6......	2.846	2.587				0.654	0.328	90.9			23.0	11.9
	7......	1.744	1.581				0.366	0.206	90.6			21.0	11.8
	8......	0.784	0.731				0.176	0.072	93.3			22.5	9.2
Total.........		13.481	12.247				3.010	1.497					
Average.......		1.926	1.750				0.430	0.214	90.9			22.3	11.1

Water period. 10 days.	9	1.048	0.923	0.921	0.536	0.386	0.233	0.138	88.0	51.1	36.8	22.2	13.2
	10	1.837	1.713	1.723	1.085	0.638	0.380	0.194	93.2	59.1	34.7	20.7	10.6
	11	1.158	1.087	1.091	0.685	0.406	0.241	0.072	93.9	59.2	35.1	20.8	6.3
	12	2.577	2.398	2.405	1.372	1.033	0.571	0.214	93.0	53.3	40.1	22.2	8.3
	13	3.133	2.678	2.700	1.443	1.257	0.713	0.376	85.5	46.1	40.1	22.8	12.0
	14	1.896	1.706	1.767	1.019	0.748	0.419	0.192	90.0	53.8	39.5	22.1	10.1
	15	2.389	2.059	2.165	1.083	1.081	0.589	0.242	86.2	45.4	45.3	24.7	10.1
	16	1.144	1.015	1.032	0.523	0.509	0.264	0.140	88.7	45.7	44.5	23.1	12.3
	17	0.811	0.806	0.787	0.425	0.362	0.207	0.102	99.4	52.4	44.7	25.5	12.6
	18	2.567	2.377	2.353	1.343	1.010	0.630	0.232	92.6	52.3	39.3	24.5	9.0
	19	0.818	0.790	0.808	0.445	0.363	0.205	0.075	96.5	54.4	44.4	25.1	9.2
Total		19.378	17.551	17.752	9.958	7.794	4.452	1.978					
Average		1.938	1.755	1.775	0.996	0.779	0.445	0.198	90.6	51.4	40.2	23.0	10.2
Final period. 4 days.	20	0.943	0.829	0.828	0.425	0.403	0.213	0.146	87.9	45.1	42.7	22.5	15.4
	21	1.855	1.675	1.703	1.015	0.688	0.429	0.196	90.3	54.7	37.1	23.1	10.6
	22	2.045	1.861	1.864	1.068	0.796	0.446	0.199	91.0	52.2	38.9	21.8	9.8
	23	2.251	2.086	2.158	1.243	0.915	0.556	0.230	92.7	55.2	40.6	24.7	10.2
	24	0.538	0.493	0.502	0.195	0.308	0.126	0.059	91.7	36.2	57.2	23.4	10.9
Total		7.631	6.944	7.055	3.946	3.109	1.769	0.830					
Average		1.908	1.736	1.764	0.987	0.777	0.442	0.207	91.0	51.7	40.7	23.2	10.9

values for the residue nitrogen. The percentage of the total nitrogen found in this form during the preliminary period, 11.1, fell to 10.2 in the water period and rose to 10.9 in the final. Similar variations, and in the same direction, were noted with W. Attention may be called again to the satisfactory agreement of the values for bacterial + soluble nitrogen with the values of the sum of these two determined separately, which thus furnishes a valuable check on the determinations.

The protein data on Subjects W and E during this experiment on moderate water drinking with meals do not justify the drawing of any but negative conclusions; they do not show that the use of water was attended by any undesirable results. The data obtained on the utilization of carbohydrate and fat during this period, which are presented in the following and preceding papers, show that where analytical methods are sufficiently exact to give significant results the effect of moderate water drinking is in the same direction as that of copious water drinking, though much less marked.

Copious Water Ingestion by an Individual Accustomed to Taking Considerable Water with Meals.

Following the preceding experiment, a period of six days formed the preliminary period for this experiment, the subject of which was E. The diet was the same as before and at the beginning of the 5-day water period the nitrogen balance was as follows:

Nitrogen in feces	1.957
Nitrogen in urine	12.775
Nitrogen in excreta	14.732
Nitrogen in food	14.761
	+0.029

Discussion of Data on Subject E, Table V.—Although both carbohydrate and fat data (discussed in other places) show differences that signify an increased utilization of these foodstuffs during the ingestion of one and one-third liters of water additional with each meal, a comparison of the data on the excretion of nitrogen in its various forms during the three periods of this experiment allows no positive conclusions to be drawn. The differences are too small to be significant. A negative conclusion, however, is entirely justifiable, when it is seen that the absorption of over four liters of water during the day, and most of this taken during the meals, had no untoward effect upon the digestion and absorption of the food. The probable reason for the fact that no change in the direction of better digestion could be noticed is that Subject E habitually took considerable amounts of water with his meals, and the experimental conditions were thus little different from the usual régime.

TABLE V.—SUBJECT E.

		Nitrogen distribution. Total fecal nitrogen.	Bacterial + soluble nitrogen.	Bacterial soluble separate.	Bacterial nitrogen.	0.2 per cent. HCl soluble nitrogen.	Acid-alc.-soluble nitrogen.	Residue nitrogen.	Percentages of total fecal nitrogen found in Bacterial + soluble.	Bacterial.	0.2 per cent. HCl soluble.	Acid-alc.-soluble.	Residue.
Prel. period, 6 days.	1	0.572	0.517	0.521	0.307	0.214	0.131	0.067	90.4	53.7	37.4	22.9	11.7
	2	1.116	1.051	1.094	0.692	0.402	0.273	0.073	94.2	62.1	36.0	24.5	6.5
	3	3.036	2.821	2.898	1.715	1.183	0.706	0.233	92.9	56.5	39.0	23.2	7.7
	4	1.940	1.813	1.836	1.088	0.748	0.451	0.176	93.5	56.1	38.6	23.3	9.1
	5	2.104	2.003	2.066	1.205	0.861	0.489	0.174	95.2	57.3	40.9	23.2	8.3
	6	2.383	2.175	2.225	1.264	0.961	0.521	0.252	91.3	53.1	40.3	21.9	10.6
	7	0.591	0.553	0.570	0.364	0.206	(0.080)	0.042	93.7	61.5	34.9	(13.5)	7.1
Total		11.741	10.933	11.210	6.635	4.575	2.650	1.016					
Average		1.957	1.822	1.868	1.106	0.763	0.457	0.169	93.1	56.5	39.0	(23.4)	8.7
Water period, 5 days.	8	1.119	1.026	1.069	0.640	0.424	0.250	0.115	91.7	57.1	37.9	22.4	10.3
	9	0.627	0.590	0.606	0.365	0.241	0.143	0.050	94.1	58.2	38.5	22.8	8.0
	10	3.633	3.429	3.512	2.040	1.472	0.756	0.292	94.4	56.2	40.5	20.8	8.0
	11	1.216	1.103	1.130	0.659	0.471	0.285	0.103	90.7	54.2	38.8	23.4	8.5
	12	2.250	2.095	2.178	1.081	1.097	0.570	0.225	93.1	48.1	48.7	25.3	10.0
	13	0.994	0.885	0.916	0.528	0.389	0.213	0.077	93.8	55.8	41.2	22.6	8.2
Total		9.788	9.128	9.411	5.312	4.094	2.216	0.861					
Average		1.958	1.826	1.882	1.062	0.819	0.443	0.172	93.3	54.3	41.8	22.6	8.8
Final period, 3 days.	14	1.790	1.658	1.712	1.042	0.670	0.389	0.189	92.6	58.2	37.4	21.7	10.6
	15	1.336	1.241	1.283	0.767	0.516	0.304	0.111	92.9	57.4	38.6	22.8	8.3
	16	2.800	2.561	2.664	1.555	1.109	0.607	0.250	91.5	55.5	39.6	21.7	8.9
	17	0.340	0.303	0.300	0.159	0.141	0.092	0.040	89.3	47.0	41.4	27.0	11.8
Total		6.265	5.763	5.958	3.523	2.435	1.392	0.590					
Average		2.088	1.921	1.986	1.174	0.812	0.464	0.197	92.0	56.2	38.9	22.2	9.4

General Discussion.

The general conclusion from all these findings is that during water ingestion with meals there is a better digestion and a more complete utilization of the protein food and that this effect is much less marked with a small water ingestion than with a large one. It is also more or less permanent, with the result that in an individual accustomed to taking considerable water with meals the effects of decreasing or increasing the volume ingested are not immediately obvious.

There is one objection to the conclusion that this is caused by water drinking. It has frequently been observed in experiments on men that the prolonged administration of a given diet causes the enzyme content of the digestive juices so to change as to be best adapted to digesting the food. It might be argued, therefore, that although the food was as well digested during the latter part of these experiments as in the beginning, this was a result of adaptation which counteracted the undesirable effects of water drinking. A comparison of the data of the final periods with those of the water periods is sufficient to show that the withdrawal of water was accompanied by a pronounced change in favor of the water drinking, or by no appreciable change in digestibility and utilization.

Any supposed effect of adaptation is also counterbalanced by the effect of loss of appetite due to the monotony of the diet. London and Pevsner[15] found that in dogs the stomach contents were more rapidly passed on to the duodenum when the factor of appetite was present than when it was absent. They conclude that the larger amount of secretion, that is, the appetite juice, was the cause. If there is any increased efficiency in "appetite" juice over the ordinary secretion in man then the digestive power of all the juices is at least not increased by the factor of appetite after partaking of over one hundred meals that were absolutely uniform in the kind and quantity of food they contained.

Evidence has been adduced in another place to show that the action of water is not such as to cause undigested food particles to be washed through the pylorus prematurely, and thereby place a more than proportionate burden upon the lower digestive tract. That a premature opening of the pylorus, resulting in a shortening of gastric digestion, is uneconomical, has been shown by Cohnheim.[16] The importance of the stomach in protein digestion is not clear despite extensive experimentation bestowed upon the subject.

London and Polovzova[17, 18] found that with but few exceptions proteins are not absorbed in the stomach, but that with few exceptions most proteins are made soluble in the stomach to about 78 per cent., the ratio between proteoses, peptones and residual substances being 59.3, 32.9, 7.8. The soluble products of gastric digestion are quickly attacked by the intestinal juices. Examination of stomach contents[19] reveals the fact that peptones, peptides and amino acids may be absorbed; while it is

shown that the enzymes of the stomach have the ability completely to hydrolyze proteins to these end-products, yet it is also shown that the length of time which pepsin requires to bring this about is far in excess of the time in which protein remains in the stomach.

The importance of the stomach in protein assimilation has been emphasized recently by Carrel, Meyer and Levene,[20] who showed that after removal of the larger part of the small intestin, although the absorption of ingested protein is diminished, the rate of assimilation and retention of the absorbed protein follows the same course as in normal animals. They conclude that the stomach and not the intestin is the most important organ for protein assimilation. London and Dmitriev[21] showed that the removal of the small intestin in a dog results in the death of the animal in about five weeks. Ordinarily, if as much as seven-eighths of the small intestin is removed, carbohydrate and especially protein assimilation rapidly return to normal but not so with the assimilation of fat. Somewhat similar results have been obtained by Underhill.[22] After resection of 80 per cent. of the small intestin Axhausen[23] found that the absorption of protein as well as of fat was very much lower than normal. Results obtained after experimental removal of various portions of the alimentary tract are always subjected to this correction that the different organs may change their function and character in the direction of compensation. Thus, after gastrectomy in dogs, Carrel, Meyer and Levene[24] observed a high nitrogen retention which disappeared in ten to twelve weeks after the operation. The explanation suggested is that the pancreatic and intestinal secretions that are minimal immediately after gastrectomy return to normal at a later period and protein is again fully digested before absorption. They also note a hypertrophy of the upper end of the duodenum after gastrectomy.

Since the presence of water along with food in the stomach is hardly of long enough duration to affect either the food or the mucous membrane, the changes for the better digestion and utilization of the protein material that have been observed must take place principally in the intestin. Some experimental work has been done on the absorption of proteins by living membranes. Zunz[25] in experiments on dogs upon protein digestion and absorption in the stomach and small intestin *in situ* has shown that the osmotic pressure of the solutions of protein introduced scarcely changes in the stomach when this is tied off, but in the small intestin it tends toward that of the blood and usually becomes lower than this. Surface tension is lower than that of the blood in both the stomach and intestin. With low proteose content the surface tension decreases in both regions. In the intestin, Zunz concludes, the digestive processes tend to bring the concentration, osmotic pressure and surface tension of the contents to the optimum for absorption. The organism itself seems to strive to secure a dilution of the products of digestion such that they can be most readily and completely absorbed.

The phenomena of absorption still lack a unifying physical explanation; in fact, each investigation seems to disclose new and unknown factors. Filtration, osmosis, the selective action of membranes and the nature and behavior of colloids are some of the important factors, upon an understanding of which the solution of the many problems depends.

Conclusions.

Without attempting to suggest any further explanations than those given at the end of the preceding paper, it may be said that the ingestion of large amounts (1000 cc.) of water with meals caused the protein constituents of the food to be more completely utilized, as shown by a decrease in all forms of nitrogen in the feces, including bacterial, 0.2 per cent. hydrochloric-acid-soluble, acid-alcoholic extractive, and residue nitrogen.

When 500 cc. of water were taken with meals no significant changes in protein utilization could be observed, as there were in fat and carbohydrate; the protein data do, however, admit of the negative conclusion, that absolutely no undesirable effects were to be observed as a result of the ingestion of 500 cc. of water with the meals. Even when over four liters of water were taken daily, with the meals, there was no indication of untoward effects as a result.

As before, the beneficial results of water ingestion with meals were not transitory, but were more or less permanent, extending beyond the time of the experimental period.

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STUDIES ON WATER DRINKING: X. FECAL OUTPUT AND ITS CARBOHYDRATE CONTENT UNDER THE INFLUENCE OF COPIOUS AND MODERATE WATER DRINKING WITH MEALS.

By H. A. Mattill.

Introduction.

It has been said that the amount of feces, as well as its nitrogen content, depends entirely upon the cellulose content of the food materials, the first being the result of the inability of the organism to digest cellulose, the second being due to the increased desquamation of intestinal epithelium as a result of heightened peristalsis and to an accompanying increase in the amount of digestive fluids secreted.

Aside from possible traces of the less common complex carbohydrates, the only carbohydrates ever present in normal feces under ordinary conditions are cellulose and starch. It has been shown by Lusk[1] that the decomposition of cellulose does not result in the formation of glucose, and its nutritive value is probably in the fatty acids formed from it. In a study of the digestibility of carbohydrate, therefore, a consideration of the possible digestion of cellulose is unnecessary.

The source of starch in the feces is ingested vegetable food, the cellulose envelopes of which, as a result of insufficient disintegration, have not become accessible to the action of the digestive juices. The manner of preparing the food has much to do with the extent of this disintegration; the efficiency of the mastication also plays a part, and the activity of the digestive juices and the extent of the churning to which the food is subjected in the intestin also have an influence. All other conditions remaining the same, the amount of carbohydrate found in the feces should furnish some indication as to the digestibility of carbohydrate in the organism, as well as to the extent of cellular disintegration by which it has become available. In the series of observations reported in the preceding papers on the utilization of protein and fat under the conditions of water drinking with meals attention was also paid to the comparative amounts of fecal dry matter and moisture, and to the utilization of carbohydrate, although the diet consisted of almost completely available food and contained little cellulose.

The early experiment of Ruzicka[2] previously referred to included certain data upon total fecal excretion. During the first 2-day period (no water with meals) the total fecal dry matter was 46.2 grams against 42.0 grams

in the second 2-day period when water was taken with meals. The total dry matter ingested during the first (no water) period was 783.3 grams, while the dry matter ingested in the second period was 842.5 grams. The carbohydrate intake and excretion (obtained by difference) for the two periods were as follows:

	First period (no water). Grams.	Second period (water). Grams.
Ingesta................	357.4	384.4
Excreta................	6.9	6.3

It is thus seen that the ingestion both of total dry matter and of carbohydrate was larger in the water period than in the period when no water was taken with the meals, while the excretion both of total dry matter and of carbohydrate was smaller when water was taken with meals than when none was taken. The diet was one of bread and meat, and analyses are given which show that the feces were of relatively the same composition in both periods, 100 grams of the dry substance yielding 14.9 and 15.0 grams, respectively, of carbohydrate.

In the investigation of Fowler and Hawk[3] referred to in the previous paper the elimination of fecal dry matter and moisture during the period of water ingestion with meals was much less than during either the fore or after period. No data were obtained on carbohydrate utilization.

Methods.—In the paper on fat utilization will be found a description of the method of collecting and preparing the sample. *Moisture.* Moisture was determined, during one experiment, in porcelain crucibles, during a second in lead caps. The latter method is much more satisfactory. The samples were first air-dried for two or three days, and then in an oven at 102°, for two or three days.

Carbohydrate.—Carbohydrate was determined by a modification of the method of Strasburger.[4] The procedure was as follows: Five to 10 grams of feces were weighed out into a 200 cc. Erlenmeyer flask, and 5–7 grams of bone-black were added along with 100 cc. of 2 per cent. hydrochloric acid. This mixture was boiled for one and one-half to two hours under a reflux condenser, allowed to cool, made alkaline with sodium hydroxide to precipitate calcium salts and filtered with suction. Ordinarily this took considerable time. The filtrate was clear and varied in color from a dark straw to entire absence of color. This solution was approximately neutralized and its reducing power was determined in an aliquot portion by the method of Benedict.[5] The procedure of Strasburger involves the determination of sugar by the copper thiocyanate method of Volhard-Pflüger, and the time and labor required in this method

are considerably greater than for the method used in these experiments. In most cases, also, satisfactory duplicates were obtained. The solutions as prepared for the determination could never be allowed to stand any length of time with neutral or slightly alkaline reaction as the development of molds brought about decompositions and destruction of sugar. When they were left standing they were always acidified.

Experiments on Copious Water Drinking with Meals.

The routine of the experiment on Subjects H and W has been described in a preceding paper. The diet of both men contained carbohydrate as follows:

	Amount (per meal).	Carbohydrate.
Graham crackers	150.0 grams	108.8 grams
Peanut butter	20.0	3.2
Milk	450.0 (cc.)	25.7
Butter (carbohydrate negligible)	25.0	
	Total,	137.7

For water ingestion see paper on fat utilization.

Discussion of Data from Subject W, Table I.—The average amount of feces passed per day during the preliminary period was 177.8 grams, during the water period 119.3 grams, and during the final period 121.1

TABLE I.—SUBJECT W.

	Number of stool.	Weight. Grams.	Per cent. dry matter.	Amount dry matter. Grams.	Amount moisture. Grams.	Carbohydrate Grams.
Prel. period. 3 days	1	147.0	27.33	40.2	106.8	1.955
	2	182.5	25.86	47.2	135.3	2.71
	3	66.0	27.21	18.0	48.0	1.12
	4	138.0	23.67	32.7	105.3	1.78
Total		533.5	...	138.1	395.4	7.565
Average (per day)		177.8	25.9	46.0	131.8	2.52
Water period. 5 days	5	214.0	13.17	28.2	185.8	2.09
	6	25.2	23.24	5.9	19.3	0.26
	7	94.0	27.34	25.7	68.3	1.51
	8	102.8	28.85	29.7	73.1	1.56
	9	121.5	26.05	31.6	89.9	1.87
	10	39.0	29.83	11.6	27.4	0.47
Total		596.5	...	132.7	463.8	7.76
Average (per day)		119.3	22.2	26.5	92.8	1.55
Final period. 3 days	11	104.5	25.48	26.6	77.9	1.40
	12	134.0	25.83	34.6	99.4	2.09
	13	26.9	31.85	8.6	18.3	0.38
	14	98.0	26.10	25.6	72.4	1.55
Total		363.4	...	95.4	268.0	5.42
Average (per day)		121.1	26.3	31.8	89.3	1.81

grams. A similar variation is observed in the fecal dry matter which decreases from 46 grams per day in the preliminary to 26.5 grams in the water period and again rizes in the final to 31.8 grams. The average daily amount of water in the feces of the preliminary period was 131.8 grams, in the water period 92.8 grams and in the final period 89.3 grams. Notwithstanding the large amount of water passed into the intestin during the water period, there was less in the feces during that time than before; the amount of water excreted in the feces in the final period was slightly less than the amount in the water period. The total amount of feces and of dry matter for the final period were only slightly higher than those of the water period and not nearly as high as those of the preliminary.

Digestion and Absorption of Carbohydrate.—The average daily excretion of carbohydrate during the preliminary period was 2.52 grams, during the water period 1.55 grams, and during the final period 1.81 grams. It appears that the effect of the large amount of water was to secure a better digestion and more complete utilization of the ingested carbohydrate, and the influence of the water extended beyond the time in which it was used.

The amount of carbohydrate in Stool No. 5, the first of the water period is 2.09 grams, the largest amount during any day of the period. This is the more striking since the entire stool contained only 28.2 grams solid matter, of which 5.8 grams were fat. The total nitrogen was also above the average, and the bacterial and extractive or acid-alcohol-soluble portions were unusually low. All of these facts indicate incomplete digestion of the food. Stool No. 5 was passed immediately after breakfast on the morning of the second day of water. Before breakfast Stool No. 4 had been passed; this contained none of the charcoal that had been taken before breakfast on the morning of the day before, the first day of the water. Charcoal was found in No. 5. W records a feeling of pressure on the first day of water as well as on the second, but on the second it seemed to increase. Stool No. 5 gives evidence from its high content of water and of foodstuffs that it was forced out before the time necessary for satisfactory digestion and absorption. Notwithstanding that this, the first stool of the water period contained undigested protein, fat and carbohydrate, nevertheless an examination of the data shows that the average daily output of those substances was markedly lowered under the influence of water ingestion.

Discussion of Data from Subject H, Table II.—The average daily amount of feces passed during the water period was less than that in either preliminary or final periods. The average amount in the period after the water is less than that in the period before the water. The average daily dry matter suffered a similar drop during the water period. The amount

of water in the feces during the water period was also less than during the preliminary or final periods showing that even with the large amounts of water sent into the intestin the amount absorbed was actually more than the excess administered.

TABLE II.—SUBJECT H.

	Number of stool.	Weight. Grams.	Per cent. dry matter.	Amount dry matter. Grams.	Amount moisture. Grams.	Carbohydrate. Grams.
Prel. period. 3 days	1	42.5	29.42	12.5	30.0	0.57
	2	87.0	26.54	23.1	63.9	1.20
	3	158.0	26.57	42.0	116.0	2.37
	4	104.0	26.21	27.3	76.7	1.80
Total		391.5	...	104.9	286.6	5.94
Average (per day)		130.5	26.8	35.0	95.5	1.98
Water period. 5 days	5	54.0	17.71	9.6	44.4	0.66
	6	81.7	27.95	22.8	58.9	1.45
	7	43.0	31.68	13.6	29.4	0.82
	8	269.5	24.33	65.6	203.9	3.89
	9	141.0	22.00	31.0	110.0	1.87
Total		589.2	...	142.6	446.6	8.69
Average (per day)		117.8	24.2	28.5	89.3	1.74
Final period. 3 days	10	101.0	23.90	24.1	76.9	1.06
	11	25.5	33.40	8.5	17.0	0.37
	12	112.0	27.90	31.3	80.7	1.71
	13	141.5	25.92	36.7	104.8	1.92
Total		380.0	...	100.6	279.4	5.06
Average (per day)		126.7	26.2	33.5	93.1	1.69

Carbohydrate.—The data from the carbohydrate determinations are not as striking as those from Subject W but the variations are in the same direction. The average daily excretion during the preliminary period, 1.98 grams, fell to 1.74 grams during the water period, and was still less, 1.69 grams per day, in the final period.

Summary.—The findings obtained in this experiment show that during the period when large amounts of water were taken with meals the total amounts of feces, of fecal dry matter and of fecal moisture were less than without the unusual amounts of water, and that a more or less permanently better utilization of carbohydrate accompanied the water drinking.

Experiments on Moderate Water Drinking.

Before considering the data obtained in the experiment on moderate water drinking a word of explanation should be given regarding Sub-

ject E. During the preceding year while he was serving as subject on another metabolism experiment and was on a uniform diet a pronounced intestinal fermentation made itself evident by a stool of high moisture content. Although he was subject to a condition of this kind even on an ordinary mixed diet he made no mention of this and was therefore accepted for the present metabolism study. The condition was one apparently peculiar to the organism and was not dependent upon such external conditions as could easily be determined and controlled. Subject W had served in the preceding experiment.

The diets of the two men were alike in composition but differed slightly in quantity.

SUBJECT W.

	Amount (per meal).	Carbohydrate.
Graham crackers	125 grams	90.6 grams
Peanut butter	20	3.2
Milk	400 (cc.)	22.8
Butter (carbohydrate negligible)	25	———
	Total,	116.6

SUBJECT E.

	Amount.	Carbohydrate.
Graham crackers	150 grams	108.8 grams
Peanut butter	20	3.2
Milk	400 (cc.)	22.8
Butter (carbohydrate negligible)	25	———
	Total,	134.8

For water ingestion see paper on fat utilization.

In addition to the weights of feces, dry matter and moisture, the values for the daily excretion of dry bacteria are also given; the values have been calculated from the bacterial nitrogen values on the basis of a nitrogen content of dry bacteria equal to 10.96 per cent.; this is more fully explained by us in a recent paper on the method for determining bacterial nitrogen.*

Discussion of Data from Subject W, Table III.—The separation of the preliminary period of low water ingestion into two parts showed a condition for carbohydrate and for total fecal output similar to that noted for fat and protein. The average amount of feces passed per day during the first part of this period was 89.0 grams, as against 104.6 grams in the second. The average daily dry matter content during the first part of this period was 23.9 grams as against 27.3 grams during the second part. The differences are small but not inconsiderable. Carbohydrate also shows an increase from 2.15 grams per day in the first part to 2.31 grams in the second. Comparing this preliminary period with that of the first experiment, the average daily amount of feces in the first experiment was

* Mattill and Hawk: *J. Exp. Med.*, 14, 433 (1911).

TABLE III.—SUBJECT W.

Period	Number of stool.	Weight. Grams.	Per cent. dry matter	Amount dry matter. Grams.	Amount moisture. Grams.	Bacterial dry substance. Grams.	Carbohydrate Grams.
Prel. period I. 7 days	1......	155.5	25.94	40.3	115.2	...	3.16
	2......	39.2	31.57	12.4	26.8	...	1.14
	3......	63.7	27.78	17.7	46.0	...	1.92
	4......	72.0	28.92	20.8	51.2	...	1.89
	5......	201.8	27.04	54.6	147.2	...	5.22
	6......	90.9	23.50	21.4	69.5	...	1.74
Total......................		623.1	...	167.2	455.9	...	15.07
Average (per day)............		89.0	26.85	23.9	65.1	...	2.15
Prel. period II. 6 days	7......	62.8	25.61	16.1	46.7	4.40	1.52
	8......	98.8	26.72	26.4	72.4	6.32	2.08
	9......	109.8	27.50	30.2	79.6	7.21	3.05
	10......	185.8	24.10	44.8	141.0	10.10	3.58
	11......	41.8	31.23	13.1	28.7	2.62	1.03
	12......	104.9	24.28	25.5	79.4	5.38	2.15
	13......	24.0	32.87	7.9	16.1	1.78	0.45
Total......................		627.9	...	164.0	463.9	37.80	13.86
Average (per day)............		104.6	26.10	27.3	77.3	6.30	2.31
Water period. 10 days	14......	31.6	23.90	7.6	24.0	1.82	0.25
	15......	147.5	27.52	40.6	106.9	8.98	2.25
	16......	75.4	26.20	19.8	55.6	5.13	1.20
	17......	144.8	27.45	39.8	105.0	9.92	2.60
	18......	63.9	26.84	17.2	46.7	4.02	1.37
	19......	115.5	27.10	31.3	84.2	7.97	2.51
	20......	26.0	27.49	7.2	18.8	1.81	0.56
	21......	169.0	26.52	44.8	124.2	11.84	4.60
	22......	127.0	24.35	30.9	96.1	8.04	2.93
	23......	152.7	23.26	35.5	117.2	9.08	3.54
Total......................		1053.4	...	274.7	778.7	68.60	21.81
Average (per day)............		105.3	26.12	27.5	77.8	6.86	2.18
Final period. 5 days	24......	60.0	24.67	14.8	45.2	3.80	1.34
	25......	119.6	23.38	28.0	91.6	7.51	2.41
	26......	51.1	27.50	14.1	37.0	4.21	1.10
	27......	142.7	25.05	35.8	106.9	10.59	2.27
	28......	81.4	27.96	22.8	58.6	6.91	1.82
	29......	53.4	30.61	16.4	37.0	4.91	1.39
Total......................		508.2	...	131.9	376.3	37.92	10.33
Average (per day)............		101.6	25.90	26.3	75.3	7.59	2.07

177.8 grams as against 89.0 in the second; dry matter 46.0 grams in the first as against 23.9 in the second; carbohydrate 2.52 grams in the first as against 2.15 in the second.

Carbohydrate.—An examination of the data upon carbohydrate excre-

tion during the ten-day water period reveals differences that are small but nevertheless in the same direction as noted in the experiment on copious water drinking. The daily average excretion in the preliminary period, 2.31 grams, fell to 2.18 grams in the water period, and was still lower, to 2.07 grams, in the final period.

Discussion of Data from Subject E, Table IV.—The findings upon the fecal output of Subject E during the three periods of this experiment show variations so small that they admit of no conclusions.

TABLE IV.—SUBJECT E.

	Number of stool.	Weight. Grams.	Per cent. dry matter.	Amount dry matter. Grams.	Amount moisture. Grams.	Bacterial dry substance. Grams.	Carbo-hydrate. Grams.
Prel. period. 7 days	1.....	88.4	20.81	18.4	70.0	...	2.48
	2.....	30.2	26.56	8.0	22.2	...	1.18
	3.....	179.2	23.01	41.2	138.0	...	4.98
	4.....	193.9	24.67	47.8	146.1	...	7.21
	5.....	76.9	26.17	20.1	56.8	..	2.37
	6.....	207.7	22.78	47.3	160.4	...	5.31
	7.....	124.6	22.30	27.8	96.8	...	3.49
	8.....	44.0	29.42	12.9	31.1	...	1.38
Total....................		944.9	...	223.7	721.2	...	28.40
Average (per day)..........		135.0	23.70	32.0	103.0	...	4.06
Water period. 10 days	9.....	76.5	22.87	17.5	59.0	4.89	2.48
	10.....	140.9	20.88	29.4	111.5	9.90	4.47
	11.....	63.8	29.16	18.6	45.2	6.25	1.55
	12.....	169.0	24.30	41.1	127.9	12.52	4.04
	13.....	247.5	19.19	47.5	200.0	13.17	4.80
	14.....	135.3	22.96	31.1	104.2	9.29	3.33
	15.....	192.4	19.58	37.7	154.7	9.88	4.18
	16.....	79.2	24.58	19.5	59.7	4.77	1.33
	17.....	55.9	27.17	15.2	40.7	3.88	1.48
	18.....	173.5	24.91	43.2	130.3	12.25	3.68
	19.....	51.5	27.98	14.4	37.1	4.06	1.17
Total....................		1385.5	...	315.2	1070.3	90.85	32.51
Average (per day)..........		138.6	22.73	31.5	107.1	9.09	3.25
Final period. 4 days	20.....	67.3	23.60	15.9	51.4	3.88	1.42
	21.....	117.8	26.08	30.7	87.1	9.26	2.76
	22.....	147.7	23.19	34.3	113.4	9.74	3.46
	23.....	145.9	26.49	38.7	106.2	11.34	4.53
	24.....	31.2	31.55	9.8	21.4	1.78	0.81
Total....................		509.9	...	129.4	380.5	36.0	12.98
Average (per day)..........		127.5	25.34	32.3	95.2	9.0	3.25

Carbohydrate.—The average daily excretion of carbohydrate dropped from 4.06 grams to 3.25 grams during the water period, and stayed at

the same value in the final. This is a small difference to be significant but on a uniform diet the evidence is creditable; it points to the same conclusion for moderate water drinking that has been reached up to this time for copious water drinking.

On the basis of these data it appears that the effect of a moderate amount of water with meals is in the same direction as when large amounts are used, although the differences observed are much smaller and not as uniformly found as with the copious amounts of water. Absolutely no harmful results could be detected.

Copious Water Drinking by an Habitual Water Drinker.

The experiment of 14 days, during the 5-day water period of which Subject E took 1333 cc. of water additional with each meal, remains to be considered.

TABLE V.—SUBJECT E.

	Number of stool.	Weight. Grams.	Per cent. dry matter.	Amount dry matter. Grams.	Amount moisture. Grams.	Bacterial dry substance. Grams.	Carbohydrate Grams.
Prel. period. 6 days	1	35.2	28.88	10.2	25.0	2.80	1.02
	2	66.0	28.48	18.8	47.2	6.32	2.03
	3	202.2	24.65	49.8	152.4	15.64	5.59
	4	129.2	24.89	32.2	97.0	9.92	3.17
	5	161.3	21.43	34.6	126.7	10.99	3.73
	6	171.8	22.61	38.8	133.0	11.54	4.43
	7	34.6	27.24	9.4	25.2	3.32	0.97
Total		800.3	...	193.8	606.5	60.52	20.94
Average (per day)		133.4	24.21	32.3	101.1	10.09	3.49
Water period. 5 days	8	90.3	20.15	18.2	72.1	5.83	2.14
	9	37.2	27.33	10.2	27.0	3.33	1.06
	10	249.4	23.57	58.8	190.6	18.61	7.72
	11	74.7	26.57	19.9	54.8	6.01	1.52
	12	258.0	14.81	38.2	219.8	9.86	6.42
	13	52.6	30.23	15.9	36.7	4.81	1.23
Total		762.2	...	161.1	601.1	48.47	20.12
Average (per day)		152.5	21.12	32.2	120.2	9.69	4.02
Final period. 3 days	14	128.3	23.09	29.6	98.7	9.50	3.07
	15	86.4	24.34	21.0	65.4	7.00	1.51
	16	206.5	21.56	44.5	162.0	14.19	3.06
	17	50.6	11.06	5.6	45.0	1.45	0.43
Total		471.8	...	100.8	371.0	32.14	8.07
Average (per day)		157.3	21.36	33.6	123.7	10.72	2.69

Discussion of Data from Subject E, Table V.—An examination of the data in Table V shows that the average amount of feces excreted per day was 133.4 grams during the preliminary period, 152.5 grams during the

water period, and 157.3 grams in the final period. This marked increase during the water and final periods is not evident from the values for dry matter. During the preliminary period this averaged 32.3 grams per day, during the water period 32.2 grams per day, and during the final 33.6 grams per day, values which are strikingly uniform.

The apparent increase in the average daily amount of feces was thus due to water only, and it would seem that the absorption limit of water in the intestin had been reached. While no difficulty was experienced in drinking the large volume of water, the limit for its absorption had been passed. In the case of Subject W in the first experiment there was no evidence of having reached the absorption limit, while some difficulty was at first experienced in ingesting and disposing of the large quantity of water. This would lead to the conclusion that individuality and dietary habit are important factors.

Carbohydrate.—The average daily excretion of carbohydrate rose from 3.49 in the preliminary period to 4.02 in the water period, and fell to 2.69 in the final period. Stool No. 12 weighing 258 grams contained 6.42 grams of carbohydrate and only 38.2 grams of solid matter; there was pronounced evidence of fermentation. It was passed 15 hours before the usual time and was evidently the result of the intestinal conditions previously mentioned, to which E was subject at times. A larger amount of undigested material than was usual might therefore be expected, and its appearance could not be attributed to the effect of the water. The fall in excreted carbohydrate during the final period is marked, and shows rather conclusively that the high daily average output during the water period was not due to the fact that water interfered with the digestion of ingested carbohydrate but rather that the unusual finding during the water period may logically be explained as above.

Discussion.

The findings of decreased fecal output, both dry matter and moisture, and a decreased elimination of carbohydrate during the periods of water drinking indicate a more complete absorption of both water and dissolved material, with the exceptions noted above. It has been seen, in the preceding papers, that this decreased excretion of solid matter was the result also of a better utilization of the nitrogen (protein) and fat of the diet.

If drinking water with meals brought about a more rapid emptying of the stomach, the carbohydrates might reasonably be expected to give the first evidence of this fact because of all the foodstuffs carbohydrates are normally the first to leave the stomach and a shortening of the time of their sojourn there might mean incomplete hydrolysis of starch by salivary amylase. In experiments on dogs London and Polovzova[6]

have shown that sucrose and erythrodextrin alone suffer a slight hydrolysis in the stomach, due not to enzymes but to hydrochloric acid, and that under no conditions are carbohydrates absorbed in the stomach. In the duodenum hydrolytic cleavage is very extensive but absorption does not begin until the upper ileum is reached where the greater portion of carbohydrate is absorbed. The great importance of the duodenal juices in carbohydrate digestion is hereby emphasized.

This evidence may be of less value because of the fact that the saliva of the dog has at most but a slight amylolytic power. [6a, 6b, 6c]

In this connection it should also be noted that certain experiments in this laboratory[7] have shown that the production of pancreatic amylase is increased under the influence of water drinking, as would be supposed, and this fact may account in part, for the better utilization of carbohydrate.

As to the absorptive activity of the stomach toward carbohydrates, von Mering[8] concluded from some of his observations that the various sugars could be absorbed in the stomach, absorption being dependent upon the concentration of the solution; that below 5 per cent. glucose was not sensibly absorbed.

The experiments upon the absorption of carbohydrate solutions of different concentrations in the intestin have been very clear in showing the acceleration of absorption by dilution. In experiments on dogs with intestinal fistulas Kaoru Omi[9] has found that in the absorption of solutions of sodium chloride and glucose the percentage of sodium chloride and glucose absorbed depends on the concentration of the solutions introduced and is maximum for isotonic solutions. The absorption of cane sugar is maximum at lower than isotonic concentration. The amount of water absorbed diminishes with increasing concentration of the solute and at slight hypertonicity absorption is checked.

London and Polovzova[10] have made similar experiments with solutions of glucose on dogs with intestinal fistulas and the following are their findings. With increasing concentrations of the glucose solutions introduced, absorption of water in the intestin diminishes progressively. With higher concentrations a diluting secretion begins to flow from the wall of the intestin; its amount runs parallel with increasing concentration of the glucose solution, and at its maximum it may amount to one-half the total quantity of blood in the animal. By this dilution and also by absorption of sugar the concentration of the solution is brought down to 6–8 per cent., a dilution at which absorption takes place very readily in the lower intestinal tract. The secretion of the diluting fluid begins with the coming in of the first glucose solution and continues fairly uniformly. Dilute glucose solutions seem better adapted to absorption than concentrated ones. In the lower portions of the intestinal tract the con-

centration tends toward a value that is lower than isotonic. The diluting secretion has a small amount of nitrogen (0.1 per cent.) and possesses a kinase, so that in part at least it represents an increased intestinal secretion. For concentrated solutions absorption seems to take place in two stages: in the proximal portion of the intestin the proper dilution is reached, in the distal portion absorption takes place. The intestinal wall differs from the stomach wall in that the latter does not dilute concentrated solutions. The absorption of water and of dissolved substances must be considered as two independent and distinct processes, brought about by different factors. The ability to regulate automatically the concentration of substances to be absorbed is believed to be a part of the function of the digestive juices.

Applying these findings to the experiments on water drinking with meals the explanation for the more complete digestion and absorption of carbohydrates during the period of water ingestion is facilitated. Increased dilution is the effective factor. While it would seem in these experiments that the water taken with a given meal is voided in the urine before the bulk of the food material of that meal has reached the intestin, nevertheless some of the food must be carried along with the water. And further, since absorption is going on more or less continuously in the intestin, the water taken with one meal aids in diluting the products of the previous meal which are in the intestin. Not only is enzyme action more complete in dilute solutions but such solutions are also better adapted to absorption. When the solutions to be absorbed are not dilute the organism must first make them so by pouring out a diluting secretion; if they have been made dilute, the organism is spared this task.

It has been shown by Mosenthal[11] that nitrogen to the amount of about 35 per cent. of the food nitrogen of a mixed diet is daily secreted in the succus entericus of dogs, and that of this quantity an amount equal to 10 per cent. of the food nitrogen is excreted in the feces and an amount equal to 25 per cent. of the food nitrogen is reabsorbed. The metabolic significance of this reabsorption is not understood, but it is probably of great importance. In cases of defective absorption the amount of fecal nitrogen may easily be increased from this source and thus lead to the drawing of wrong conclusions. It is obvious that for various reasons, this possibility need not be considered in connection with water drinking.

That secretion and absorption are exothermic in their nature and require energy has frequently been shown and again recently,[12, 13] and in their first report of observations on the stimulating action of water upon the gastric, mucous membrane, Foster and Lambert[14] suggest that a physiological basis for the objection to copious water drinking with meals may be found in the increased activity to which the glands are thus

forced. If glandular activity requires as much energy as other forms of activity, this special and excessive secretion may be a form of extravagance leading to the weakening and premature death of the cells. In fact, they find that the juice excited by a meal following 5 or 6 hours after a meal with water and its greater demands is less in amount than a normal meal should excite. Whether this is a true gland fatigue, and whether or not such observations point to a premature death of the cells can be determined only by histological examinations.[1] Applying this reasoning to the secretory activity of the intestin a similar form of extravagance may be said to be caused in the intestin by insufficient water ingestion with meals. If there is a loss in energy in the increased flow of gastric juice by water drinking, this is more than compensated by better digestion and absorption of food in the intestin, while the needless energy used in preparing a diluting secretion for food which is too concentrated is a direct loss uncompensated by any subsequent factors making for better utilization of the food. The preservation of the digestive efficiency of the intestin is probably of much greater importance than that of the stomach, since it may be that the main offices of the stomach are not those of a digestive nature.[15]

Conclusions.

(1) It has been shown that in men living on a uniform diet the addition of 1000 cc. of water to each meal causes a decrease in the excretion of fecal material, both dry matter and moisture.

(2) Under the same conditions a decrease in excreted carbohydrate material was also observed.

(3) The better utilization of food material thus evident was not temporary but appeared to extend for some time following the use of water.

(4) The ingestion of a smaller amount of water (500 cc.) and the use of a large volume of water (1333 cc.) by one accustomed to drinking water with meals showed a similar but less marked reduction in the excretion of carbohydrate.

(5) The individual variations noted emphasize the fact that the findings on two or three men possessing different dietary habits and accustomed to ingesting varying volumes of water with meals may not be generalized.

(6) The beneficial effects noted are probably due to the stimulatory action of water upon the digestive secretions, to the increased dilution which facilitates enzyme action and materially aids in absorption, and to a conservation of the intestinal energy involved in the secretion of a diluting fluid which is necessary when insufficient water is ingested.

(7) The average daily output of dry bacterial substance for the 66 stools completely examined was 8.27 grams.

[1] Investigations of this character are contemplated.

(8) Many desirable and no undesirable effects were obtained by the use of water with meals, and in general, the more water taken the more pronounced were the benefits.

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BIOGRAPHICAL.

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